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PIPING AND RELATED PROBLEMS AT LARGE CULVERT INSTALLATIONS IN MONTANA

by

HARVEY D. FUNK

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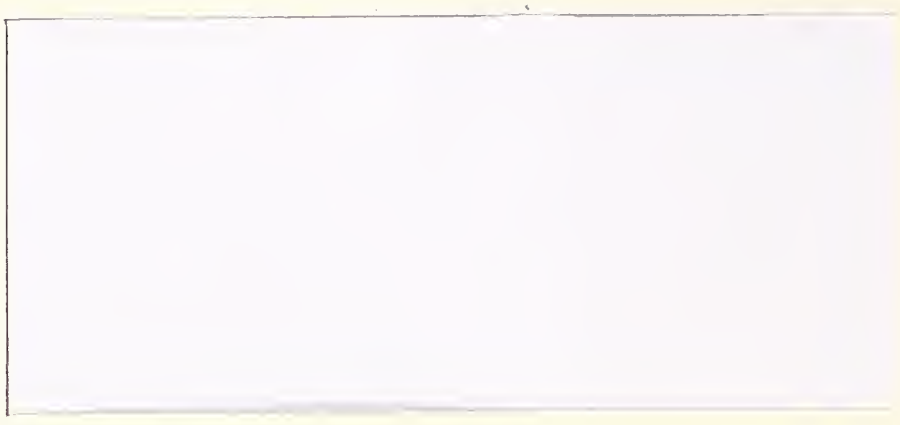

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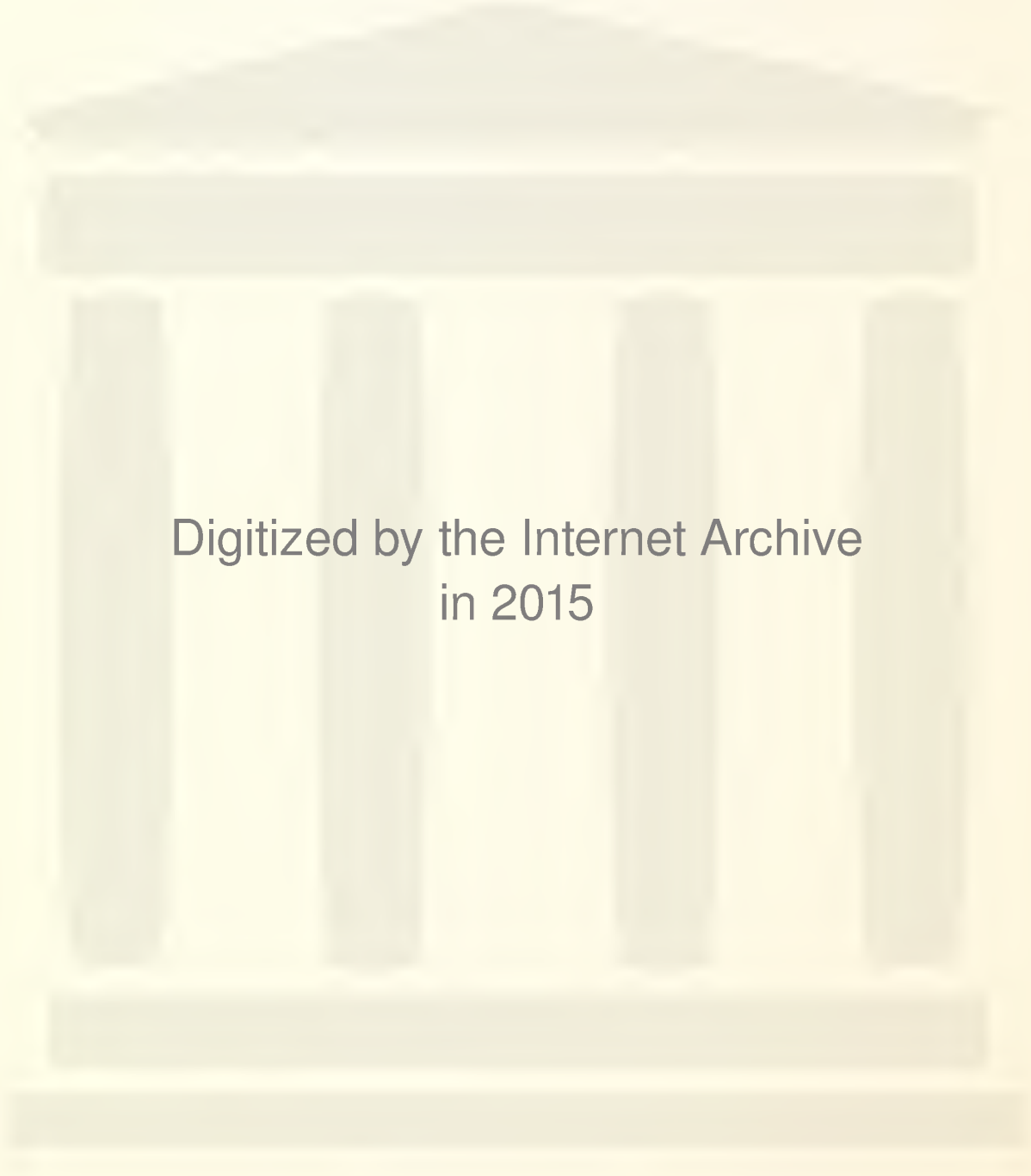
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Montana State University

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Department of
Civil Engineering & Engineering Mechanics
College of Engineering

September 30, 1965

Mr. Paul R. Devine
Planning Survey Manager
State Highway Department
Helena, Montana 59601

Dear Paul:

I am submitting herewith, as an interim report on the Large Culvert Research Project, ten copies of Harvey Funk's Thesis entitled "Piping and Related Problems at Large Culvert Installations in Montana."

Appendix D (pages 68-100) was included to provide a convenient source of reference for the identification of the 55 project culverts and a condensed summary of the culvert survey findings.

Very truly yours,

Alfred C. Scheer

Alfred C. Scheer
Associate Professor and
Project Supervisor for the
Large Culvert Research Project

ACS/g

PIPING AND RELATED PROBLEMS AT LARGE CULVERT INSTALLATIONS IN MONTANA

by

HARVEY D. FUNK

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE

in

Civil Engineering

Approved:

Head, Major Department

Chairman, Examining Committee

Dean, Graduate Division

MONTANA STATE UNIVERSITY
Bozeman, Montana

June, 1966

VITA

Harvey D. Funk, son of Mrs. Elizabeth Funk of Chinook and the late Mr. Dave Funk, was born August 20, 1936 in Chinook, Montana. He received his elementary and secondary education in Blaine County and graduated from Chinook High School in May, 1954. After two years in the Army and three years in business, he entered Montana State College the fall of 1959 and received a Bachelor of Science Degree in Civil Engineering in June of 1964. With a research assistantship, he started working towards a Master of Science Degree in Civil Engineering at Montana State College in the fall of 1964.

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The Author wishes to show his appreciation by thanking those who have helped in making this thesis possible. Thanks go to the thesis committee, especially to Professor A. C. Scheer, Major Advisor for the Author.

The study and research for the Large Culvert Research Project was made possible by the Bureau of Public Roads and the Montana Highway Commission, who sponsored the project, using Highway Planning and Research funds. Thanks go to the personnel of these agencies who assisted in the project.

Also, thanks to my wife, Marla, who assisted with this paper with her typing.

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ABSTRACT

During the course of an investigation of culverts in Montana (the Large Culvert Research Project, sponsored by the Montana Highway Department and conducted by the Civil Engineering and Engineering Mechanics Department at Montana State University), six cases of piping alongside or under road culverts were found.

In some cases, the piping was evident after a visual inspection. In other cases, piping was suspected after taking rebound hammer readings with a Schmidt hammer, an instrument designed for estimating concrete strengths. The suspected piping cases were further investigated by punching holes in the culvert plates and observing the fill through the holes. If piping existed, the piping channel could be traced by punching holes.

Soil samples were taken from the piping holes and tested in the soil mechanics laboratory. The tests revealed a range of soil types from a cohesionless sand to plastic clay.

In some cases, the piping had eroded large amounts of backfill material away from the sides of the culverts, excessively reducing the lateral support to the culverts.

In one case of well developed piping, the plates were cracked along a longitudinal seam, located at the side of a pipe-arch culvert.

It was hypothesized that excessive bending moments, due to the loading situation of no lateral support, stressed the plates to failure in the form of cracking the plates.

A computer program was developed to determine the magnitude of the bending moments that might develop under different loading conditions. The results, for the case studied, indicated that the moments developed in a culvert with no lateral support stressed the plates beyond the elastic range. The cracked plates were evidence that the plates had been stressed to incipient fracture.

It was concluded that: piping occurs in a wide variety of soil types; the Schmidt hammer is a useful tool for helping to determine the fill condition behind culvert plates; and, that piping removes backfill from around culverts, sometimes excessively, which may lead to loading conditions that develop bending moments large enough to crack the culvert plates.

It was recommended that the problem of piping be given full consideration in design and construction.

For future study, it is suggested that different plunger face-shapes be tried in the Schmidt hammer in an attempt to reduce or eliminate variations in Schmidt hammer readings.

CHAPTER I

INTRODUCTION

THE PROBLEM

A major problem which has long concerned the designers of hydraulic structures is the phenomenon of piping. Piping, an internal erosion within soil, caused by seepage, is characterized by a pipe-shaped channel, formed from the tailwater side towards the headwater side of a fill. Piping under or through dams has long been recognized as a major problem. Another area where piping is a problem is alongside and under road culverts and has become increasingly important as the size and cost of culverts has increased. This paper will deal with the problem of piping alongside and under road culverts.

During the past several years, the Civil Engineering and Engineering Mechanics Department at Montana State University has conducted an investigation of culverts in Montana through sponsorship of the Montana State Highway Department. This study, entitled the "Large Culvert Research Project", has revealed at least six cases of culvert piping in Montana. This discovery suggested that an intensive study of these sites should be made, which would involve the verification of piping, the determination of soil types, and the possibility that piping may be the cause of structural failures in the form of cracked plates.

BACKGROUND INFORMATION

The Large Culvert Research Project originated during the spring of 1963. The purpose of the project was to make a detailed survey and analysis of large culvert installations in Montana and obtain information which would lead to recommendations regarding design criteria and construction and

maintenance standards.

After a quick inspection of about 400 culverts, six feet in diameter or larger, 55 were selected at various locations throughout the state. The selections were made mainly on the basis of various problems that existed at the sites. These problems included:

sediment deposits
fill erosion
scour holes
corrosion
structural deformations
structural failures
piping

The selected culverts were given an extensive survey during the summer of 1963 and again during the summer of 1964 The surveys included:

taking photos
measurements of the culvert
level readings of the stream bed and culvert
soil samples
rebound hammer reading
hole punching

The tabulations of data obtained and pictures showing some of the failures can be found in Appendix D.

The remainder of the main body of this thesis will deal with the findings and investigations related to piping.

CHAPTER II

REVIEW OF LITERATURE

PIPING DEFINED

In 1936, A. Casagrande (1)[1] listed piping as a term used to define an internal erosion caused by seepage, with the erosion progressing backward until a pipe-shaped channel is formed from the downstream side to the upstream side. In some cases erosion starts between headwater and tailwater by means of "roofing"; that is, the arching of a harder material over a weaker material which is settling, thus, resulting in a plane of weakness or an open space through which a concentration of seepage develops.

Once a "pipe" has formed, erosion can progress rapidly, making a large channel and possibly causing a failure of the structure.

MECHANICS OF PIPING

In 1929, Charles Terzaghi (3) noted that, for water flowing vertically upward to escape, the fundamental requirement to start piping is that the upward pull exerted by the seepage water overcomes, at some point, the downward pull exerted by the force of gravity. As soon as this occurs, erosion will start, possibly forming a channel.

Terzaghi further explained the mechanics of piping with a system of flow lines and equipotential lines. For the type of flow net used, the quantity of water which flows between each pair of flow lines is equal. The danger spot, where piping would start, is on the downstream end of the flow lines, at a point where the distance between the ends of adjacent flow lines is a minimum. The upward pull exerted by the water at the danger spot

---

[1] Numbers is parentheses refer to references listed under LITERATURE CITED.

is inversely proportional to the distance between the ends of the flow lines and directly proportional to the quantity of water which flows between two lines.

PIPING ALONG A CORRUGATED METAL PIPE

Most of the concern about piping in the past has been related to dams. A structure similar to a culvert under a road was the subject of research by the Bureau of Land Management at their Earth Laboratory Branch at Denver, Colorado during 1958 (4). The Bureau had constructed numerous small earth dams for water detention and retention purposes and piping difficulties were encountered on several structures. The piping appeared to start between the earth embankment and the corrugated metal outlet pipe and, in some instances, resulted in almost complete failure of the structures. Good design and construction procedures were believed to have been followed. Therefore, the Bureau felt that valuable information could be gained from large scale laboratory model tests on corrugated metal pipe placed in a compacted embankment under various conditions of prototype design and construction.

The following conditions were among those studied during the testing program:

a. One type of soil--sandy clay, reddish brown, about 50 percent sand, slightly plastic. (This soil was shipped from a BLM project and was typical of the soils used in several dams.)

b. Loose foundation versus firm foundation.

c. Poor backfill compaction around pipe versus good backfill compaction.

d. Leaky pipe joints versus nonleaky joints.

e. Flexible metal cutoff collars versus rigid concrete cutoff collars.

f. Headwalls versus no headwalls.

Six tests for studying the above mentioned factors were performed on embankments in a large test flume under closely controlled laboratory conditions.

The equipment consisted of a 4 x 8 x 80-foot test flume in which a 12-inch diameter culvert, 18 feet long, was embedded in an earth fill. The culvert was tested with a concrete cutoff collar and a sheet metal cutoff collar.

The tests lead to the following conclusions and recommendations:

1) The foregoing tests prove conclusively, for the type of soil tested, that to prevent percolation of water around corrugated metal outlet pipes in earth retention dams, the backfill should be placed at optimum moisture and compacted to a minimum of 95 percent of Proctor maximum density.

2) Compaction is important all the way around the pipe.

3) Although well compacted bedding around the pipe will effectively stop or greatly retard piping action from leaky joints, every effort should be made to achieve watertight joints in outlet pipes.

4) Concrete cutoff collars seemed to offer these advantages over corrugated metal cutoff collars: ease of achieving better compaction around the cutoff collar, and no limitations on the size of the cutoff collar.

5) It seems advisable to install a headwall on the upstream end of an outlet pipe but these tests, being rather limited in their scope, offered no proof for or against headwalls.

6) The tests indicated that excellent, uniform compaction under the pipe may be obtained without serious uplifting of the pipe, for the series of pipe tested.

7) After a well compacted bedding is provided, it is re-

> commended that soil at optimum moisture content be compacted in two-inch layers to at least 95 percent Proctor maximum density under the pipe to the 120-degree line. Tampers equipped with rectangular tamping feet of about two-by five-inch size are recommended. Short tampers are required if trenches are narrow. Adequate air pressure for tampers must be maintained.
>
> After completion of backfill under pipe to 120-degree line, the remaining compacted backfill around the pipe is placed in the pipe trench or as the adjacent compacted embankment is constructed. Optimum moisture conditions and compaction of at least 95 percent Proctor maximum are required.

Although these tests were all performed on a small culvert, they probably have some relevance to large culverts.

MONTANA HIGHWAY DEPARTMENT SPECIFICATIONS ON CULVERT INSTALLATIONS

In the current standard specifications of the Montana State Highway Department (5), the following specifications for bedding and backfill requirements are noted for culverts: bedding and backfill for culverts is specified to be compacted to between 90 and 100 percent of maximum density, depending on the material in question. For circular and elliptical pipes, the bedding is to be shaped to fit the lower part of the pipe for at least ten percent of its overall diameter. For arch type culverts, the bedding shall conform to the full width of the slightly curved bottom, not to include the smaller radius corners.

The backfill shall be placed uniformly over the entire culvert and foundation area around the pipe in layers of not more than four inches loose thickness. The material shall be compacted to the required density with particular care exercised in uniformly and firmly tamping the backfill material under the haunches of the pipe.

Placing of embankment over the pipe, in conjunction with overall

grading operations, shall not proceed until the pipe has been covered, to a depth equal to one-half the diameter of the pipe, with properly compacted material.

The similarity can be seen between the requirements of the Montana Highway specifications for culvert bedding and backfill and the recommendations for the prevention of piping by the Bureau of Land Management in the previous section.

STRENGTH TESTS ON CULVERT PLATES

When piping removes the backfill material from portions of the culvert, a different loading condition develops because of the loss of the supporting backfill. Excessive bending moments may develop in the culvert walls and cause structural failure along longitudinal seams. Several cases of cracked plates along longitudinal seams were observed in the course of the culvert surveys. It is hypothesized that these failures were caused by bending moments in excess of the "safe moment capacity" of the seams.

An estimate of the loads necessary to crack the plates, at seams which are susceptible to this type of failure, was obtained from Bulletin 109 of the Michigan Engineering Experiment Station, entitled "Load Deflection Tests on Corrugated Metal Sections." (2) During the summer of 1951, the Michigan Engineering Experiment Station ran laboratory investigations on different types of corrugated metal sections used in the construction of culverts. Of particular interest were tests three, four, five and six which involved bending of conventional bolted structural plate sections, standard type R.

In tests three and four, the curved specimens were supported on edge with the chord vertical and tested as columns. Tests five and six were simple beam tests in which the specimens were supported at both ends and subjected to a downward force at the center.

The maximum moments resisted by the specimens during the tests were calculated by the author of this thesis with information provided in Bulletin 109. The information used pertained to single bolted sections of one, seven, and twelve-gage corrugated metal. Figure 14 on page 34 shows a plot of plate thickness versus maximum moments.

The failure moments on this graph will be used for making comparisons with moments calculated from estimated loading situations in a case study in Chapter V.

Also of interest to this study were the pictures of cracked plates from tests five and six, shown on page 30 of the Bulletin. These cracks were caused by excessive stresses due to the bending moments developed during the simple beam tests. These cracks were similar to those found in the Emigrant culvert.

The search of literature involved the investigation of many sources not cited herein; a list of these sources will be found in the Bibliography under Other Sources Investigated.

No evidence was found that the work described in this thesis had been performed previously.

CHAPTER III

CHRONOLOGY OF THE STUDY

During the initial inspection tour in 1963 for the Large Culvert Research Project, several methods for determining the condition of the backfill around the culvert were used. One method consisted of visual inspection, where often, weeds and riprap around inlets and outlets would hamper the inspection. Another method was using a geologist's hammer, striking the culvert plates from the inside and listening to and feeling the results. A distinction could sometimes be made between "hollow" sounding spots and "solid" sounding spots. Finally, in an attempt to put the inspections on a more quantitative basis, the Schmidt rebound hammer was used to take readings on the culvert walls. Several culverts were selected for detailed future study because the preliminary inspection indicated that piping existed or was suspected.

During the summer of 1963 when the first extensive survey of the project culverts was made, a systematic set of Schmidt hammer readings were taken in each culvert. During the summer of 1964, holes were punched through the culvert plates, usually where the Schmidt hammer readings indicated poor backfill conditions. Through these holes, the condition of the backfill was determined by visual inspection and by probing with a wire. With this information, a decision could sometimes be made whether or not piping existed.

Soil samples were taken from the piping holes at culverts when piping definitely existed, and from holes suspected to be piping holes.

Chapter IV will cover the details of the investigations and describe where piping was found. The Schmidt hammer readings and supporting

data from the hole punch surveys will be analysed and presented in tabular form and discussed. The results of the soil analysis will be given also.

Chapter V will be a case study of a culvert where piping and cracked plates were both found. There is a possibility that the lack of lateral support due to piping may have caused the cracked plates. To help show this possibility, a moment analysis for different loading conditions will be given.

Chapter VI will be devoted to discussion, conclusions and recommendations.

CHAPTER IV

FIELD SURVEYS AND FINDINGS

PIPING FOUND

During the initial inspection tour for the Large Culvert Research Project, several culverts with piping holes were found and others were suspected of having piping. After investigations of the sites with suspected piping were completed, several were recorded as having some degree of piping. Shown in Table I is a list of the culverts with piping, and their location. Of the six culverts with piping, four are of the 55 Large Culvert Research Project culverts and the other two, at Okeefe and Chester, were studied in addition because of the piping. For the four Large Culvert Research Project culverts, additional information can be found in Appendix D, a summary of the findings for the Large Culvert Research Project.

Emigrant Culvert

The Emigrant culvert, a pipe-arch, had no visible evidence of piping at the inlet (See Figure 1). The stream bed, both upstream and downstream, was a gravelly sand with boulders. The culvert was undermined at the outlet, and water flowing from under the culvert was visible. The undermining at the outlet can be seen in Figure 2. The hole punch survey revealed a large void along much of the left side (when facing downstream), indicating piping. This culvert will be used as a case study in Chapter V and more details will be given there.

Cardwell Culvert

The Cardwell culvert has a circular shape, 108 inches in diameter. A well developed piping hole was observed during the first inspection, as

Table I. DESCRIPTION AND LOCATION OF CULVERTS WITH PIPING

CULVERT	LARGE CULVERT RESEARCH PROJECT CULVERT NO.	TYPE & SIZE	GAGE	HIGHWAY NO.	COUNTY	CREEK NAME	PROJECT NO. & DESCRIPTION OF LOCATION
Emigrant	1	SPPA 16'-7" x 10'-1"	3	89 Alt.	Park	Eight-mile	F 217 (10) 3.5 mi. N. of Emigrant
Cardwell	6	SPPE 108"	10	359	Madison	---	S 167 1.1 mi. S. of Jefferson Island
Okeefe	---	RCP 48" double	--	10	Missoula	Okeefe	7 mi. N.W. of Missoula
Chester	---	SPPA 8' x 6'	10	County Road	Liberty	---	6 mi. S. of Chester just E. of Jct. with highway 223
Wolf Point No. 1	46	SPPE 120"	10	2	Roosevelt	---	F 84 7.1 mi. W. of Wolf Point
Wolf Point No. 2	47	SPPE 120"	10	2	Roosevelt	---	F 84 5.4 mi. W. of Wolf Point

Remarks: SPPA refers to structural plate pipe-arch
SPPE refers to structural plate pipe-ellipse
RCP refers to reinforced concrete pipe

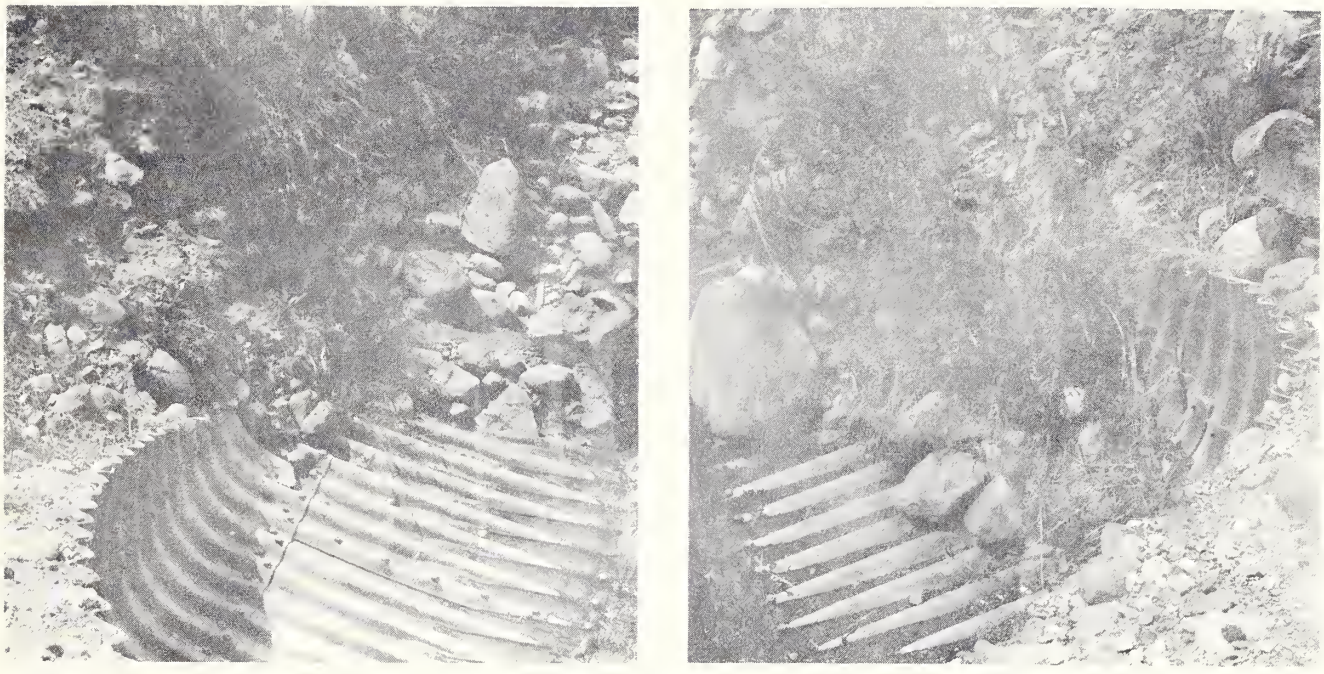


Figure 1. EMIGRANT CULVERT INLET.

There was no evidence of piping holes at either side of the inlet of this culvert.

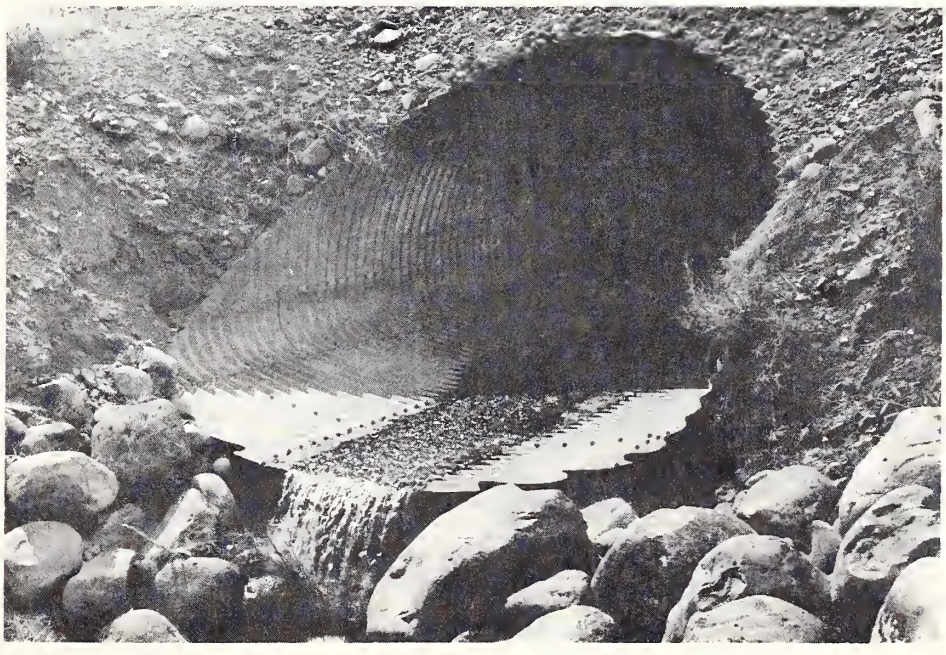


Figure 2. EMIGRANT CULVERT OUTLET.

This culvert was undermined about 15 feet. There was about as much water flowing under this culvert as through it at the time of this picture.

shown in Figure 3. The outlet piping hole was large enough to crawl into, and with a flashlight, a channel with a profile similar to that shown in Figure 4 was observed.

According to Mr. Ogan, a farmer who lives about 100 yards from this structure, piping developed the first year after installation (1958). The culvert has never flowed over half full and the piping channel has become progressively worse. Mr. Ogan said that during construction, the backfill was watered and tamped with an air hammer. The soil at this site consisted of a silt with a PI of four.

Okeefe Culvert

At this site, there are two reinforced concrete pipes, four feet in diameter, installed side by side. Piping has developed on the outsides of each culvert and between them. At the outlet, the hole between the pipes was large enough to permit a man to stand almost erect. The huge channel could be observed to extend towards the inlet for a distance of at least 20 feet (See Figure 5). The soil at this site was plastic clay with a PI of about 21-24.

Chester Culvert

This 6 x 8 pipe-arch had well developed piping holes at the sides of the inlet which apparently worked under to the floor at the outlet (See Figure 6). The soil at this site was determined to be a silty clay with a PI of 12.

Wolf Point No. 1

No well developed piping was evident at this ten-foot elliptical shaped culvert. However, the outlet was undermined about eight feet and a

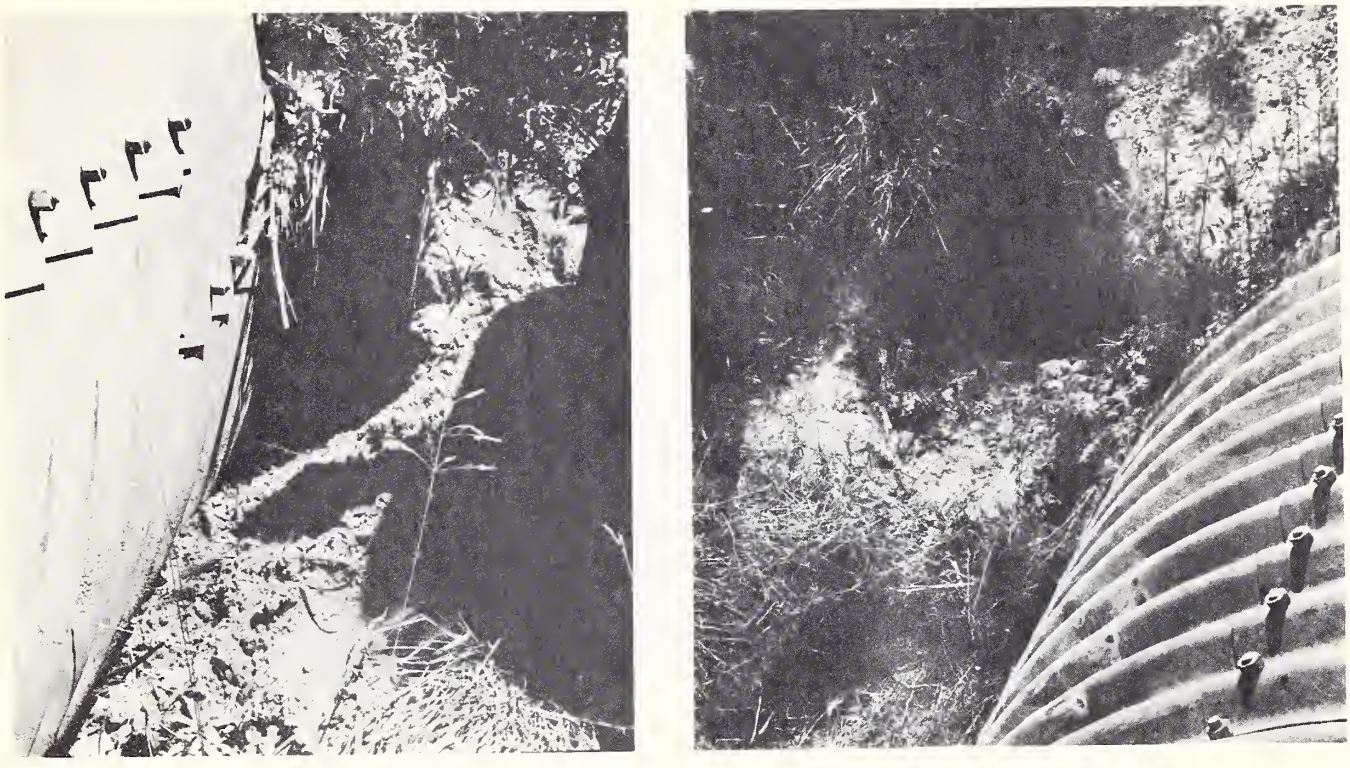


Figure 3. INLET AND OUTLET OF PIPING HOLE AT THE CARDWELL CULVERT.

The picture on the left shows the inlet piping hole which extended back as far as could be seen with a flashlight. The picture on the right shows the outlet piping hole which was large enough for a man to crawl into.

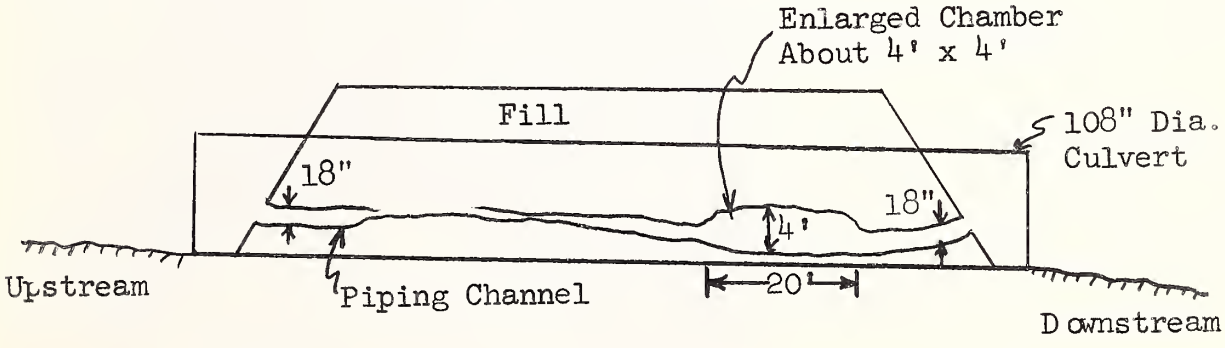


Figure 4. SKETCH OF CARDWELL PIPING CHANNEL.

Shown is a cross section of the piping channel along the right side of this culvert.

Figure 5. INLET AND OUTLET OF THE OKEEFE CULVERT.

In the picture at the top, notice how the fill between the culverts has settled. The picture on the left shows the piping hole between the pipes at the outlet.

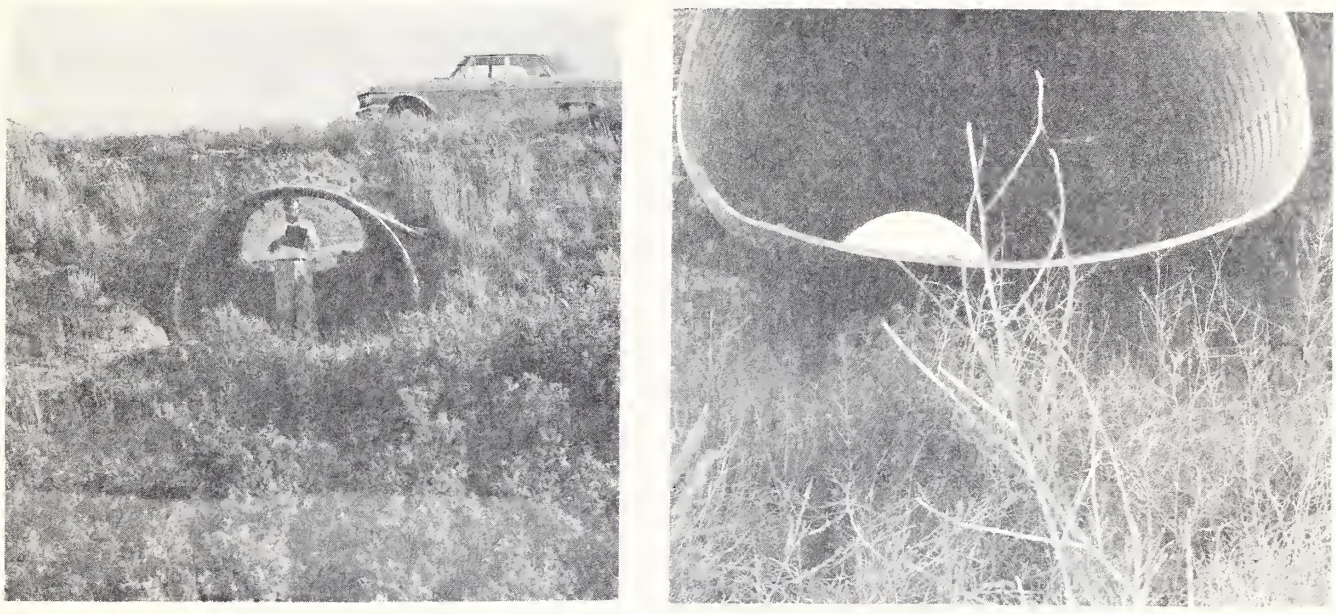


Figure 6. CHESTER CULVERT INLET AND OUTLET.

In the picture on the left, notice the piping holes at each side of the culvert inlet. The picture on the right shows the undermining and the void space under the culvert outlet.

small hole extended back from that point (See Figure 7). Possibly piping had just started. An examination of the fill, close to where piping was suspected, through holes punched in the culvert plates revealed the soil to be extremely soft and near its liquid limit. The soil was a plastic clay with a PI of 25.

Wolf Point No. 2

A small hole at the side of the outlet of this ten-foot culvert looked like a piping hole that had not reached an advanced stage (See Figure 8). The hole was investigated by digging back several feet with a shovel, and the hole continued. Exploration holes punched in the culvert plates revealed the plastic clay, with a PI of 22, to be quite soft. No channel could be traced the full length of the pipe and no hole was evident at the inlet, indicating that the piping was at an early stage.

Figure 7. WOLF POINT NO. 1 OUTLET.

This picture shows the undermining at the outlet. A small hole extended back also, but is not very visible in the picture.

Figure 8. WOLF POINT NO. 2 OUTLET.

Shown is a hole suspected to be a piping hole at the outlet of this culvert.

SCHMIDT HAMMER AND HOLE PUNCH SURVEY

The Schmidt hammer, an instrument developed to get estimates of concrete strengths through rebound readings, was used during the first extensive surveys (1963) to help determine the fill condition behind the culvert walls. Readings were taken by placing the plunger in the "valleys" of the corrugations, the plunger perpendicular to the surface, and pushing the hammer down on the plunger until the spring-loaded weight was triggered. The weight would rebound, giving a numerical reading on a scale on the side of the hammer.

The Schmidt hammer was first used in the Cardwell culvert where a known piping hole existed. With readings from this culvert, an arbitrary tentative scale was set up to estimate the firmness of the fill behind the plates. Readings below 28 were considered to indicate emptiness; between 28 and 34, soft or loose fill; and, 34 and higher, firm fill.

During the summer of 1964, in an attempt to establish a more reliable scale for indicating the backfill firmness, holes were punched, at points with known Schmidt hammer readings, with a steel punch and heavy hammer in 28 of the 55 Large Culvert Research Project culverts. Through these holes, the backfill was examined with a flashlight and an eighth-inch diameter probing wire. After the examination, the holes were sealed with General Electric silicone construction sealant.

Data was collected by the following procedure: first, a Schmidt hammer reading was taken at a desired point; second, a hole was punched; third, the fill was observed with a flashlight and probed with a wire. Notes were recorded, listing the Schmidt hammer reading and the fill con-

dition. The fill condition was recorded as firm, soft, or empty. Also, the distance the probing wire penetrated was noted. Table II shows a condensed summary of the data. Variables other than the fill condition are apparent from the data: the gage of the metal, the curvature of the plates and, of somewhat secondary importance, the orientation of the hammer. At least 80 percent of the readings taken are included in the ranges indicated in the table. A complete tabulation of all the data taken is presented in Appendix B.

Referring to Table II again, some overlapping of the ranges is evident. This points out that there is not always a distinct range of readings that indicate a fill condition. Rather, the Schmidt hammer can be considered as a tool to help determine the fill condition behind culvert plates.

One of the shortcomings of the Schmidt hammer was the shape of the plunger head. The face of the plunger has about the same curvature as the surface the readings were taken on. In some instances, upon repeated readings, the numerical readings would increase as the surface roughness in the zinc coating was flattened out. Perhaps, by using a modified plunger with a different shaped face, the variation could be eliminated or at least reduced.

SOIL TESTS ON SAMPLES FROM PIPING HOLES

Tests on soil taken from the piping holes of the six culverts listed earlier in this Chapter revealed a range of soil types from a plastic clay to a cohesionless sand. Table III shows a tabulation of the soil types. The results of the mechanical analysis of the soil samples can be seen in Appendix A.

Table II. RANGES OF SCHMIDT HAMMER READINGS FOR DIFFERENT VARIABLES.

At least 80 percent of the readings taken are included in the ranges shown.

CULVERT TYPE AND REGION OF READINGS			METAL THICKNESS AND FILL CONDITION								
			10 GAGE			8 GAGE			3 GAGE		
			EMPTY	SOFT	FIRM	EMPTY	SOFT	FIRM	EMPTY	SOFT	FIRM
	CIRCULAR	BOTTOM HALF	25±2	29±4	38±4	---	---	---	---	---	---
	ARCH	WALL	31±2	35±3	40±2	---	40±3	42±1	41±1	41±2	46±2
		18" RADIUS CORNER	30±4	39±3	44±2	40±1	44±3	50±2	41±2	44±2	50±2
		FLOOR	24±3	30±3	37±3	33±3	34±4	40 One reading	40±2	---	46±2

Table III. CLASSIFICATION OF SOIL SAMPLES TAKEN FROM PIPING HOLES.

SOIL NAME	PI	LL	TEXTURAL TYPE	AASHO CLASSIFICATION
Emigrant	0	--	Gravelly sand with boulders	A-1-b (0)
Cardwell	4	29	Silt	A-4 (8)
Okeefe	23	47	Clay	A-7-5 (14)
Chester	12	31	Silty clay	A-6 (7)
Wolf Point No. 1	25	44	Clay	A-7-5 (15)
Wolf Point No. 2	22	42	Clay	A-7-5 (13)

The fact that piping did occur in a wide range of soil types does not necessarily mean that all soils in this range are equally susceptible to piping. In almost any soil there is a possibility that a weakness zone, due to poor compaction and/or settling of the backfill, may allow the water to seep easily and piping to develop. This could take place both in the backfill alongside a culvert or in the culvert bedding. As pointed out in Chapter II, a good bedding foundation and good compaction of the backfill is necessary to prevent, or at least cut down, the possibility of piping.

A device similar to a falling head permeameter, used for getting permeability coefficients of soils, was constructed in the soil mechanics laboratory in an attempt to develop a laboratory test to determine the susceptibility of different soil types to piping. After weeks of experimenta-

tion, a satisfactory testing procedure was never developed and the tests were abandoned. However, it is reasonable to expect a cohesionless soil, such as sand or silt, to pipe more readily than a cohesive soil, such as clay, under similar conditions.

CHAPTER V

CASE STUDY

CRACKED PLATES AT EMIGRANT

The Emigrant culvert, a 16'-7" x 10'-1"-structural plate pipe-arch of three-gage metal (See Table I for other details), was chosen for a case study because of the existence of both cracked plates and piping.

The plates are cracked along the left longitudinal seam joining the 18-inch radius corner plates and the curved wall plates. The culvert is about 88 feet long and the plates are cracked for about 50 feet along the left side (looking downstream). See Figure 9 for a close-up picture of the cracked plates.

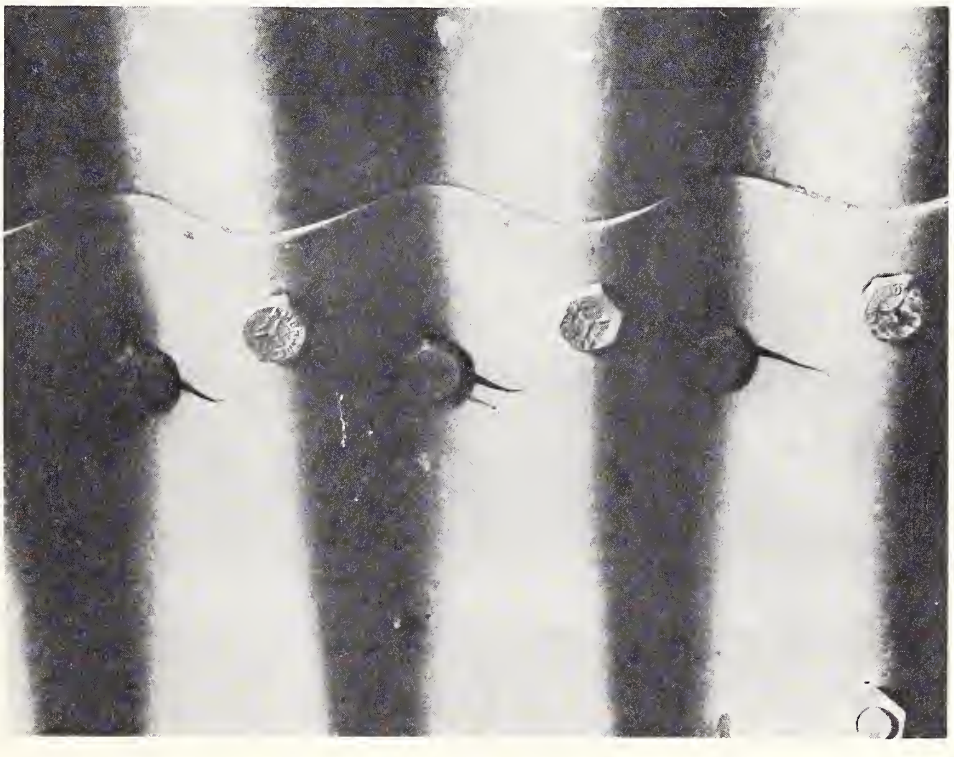


Figure 9. CRACKED PLATES IN THE EMIGRANT CULVERT.

According to Earl Best, who was project engineer during the construction of the Emigrant Culvert (during 1958), the contractor for the initial construction was held to the specifications and a close inspection was maintained throughout construction. However, the culvert "failed" when some of the backfill and bedding was eroded away from the left side, shortly after initial construction. The failure consisted of the culvert, and the overlying fill, settling excessively. A highway maintenance crew dug out part of the culvert and repaired the damage before pavement was put over it.

No cracks were noticed or reported by anyone after the repair work was finished. The cracked plates were first discovered during the first inspection of this culvert the summer of 1963. Also noticed during this inspection were the badly deformed wall sections, which were somewhat caved in, on the same side as the cracked plates. Table IV shows the heights and spans at cross sections throughout the Emigrant culvert as measured in the field.

Table IV. CROSS SECTION MEASUREMENTS OF THE EMIGRANT CULVERT.

Shown are clear span and height measurements as measured in the field. The original measurements were 16'-7" x 10'-1".

DISTANCE FROM INLET	SPAN	HEIGHT
15'	16'-8"	9'-7"
32'	17'-0"	9'-4"
44' (Middle)	17'-0"	9'-2"
60'	17'-0"	9'-2"
77'	16'-4"	9'-8"

Figure 10 shows the undeformed and deformed shapes of the Emigrant culvert as used in the structural analysis later in this Chapter.

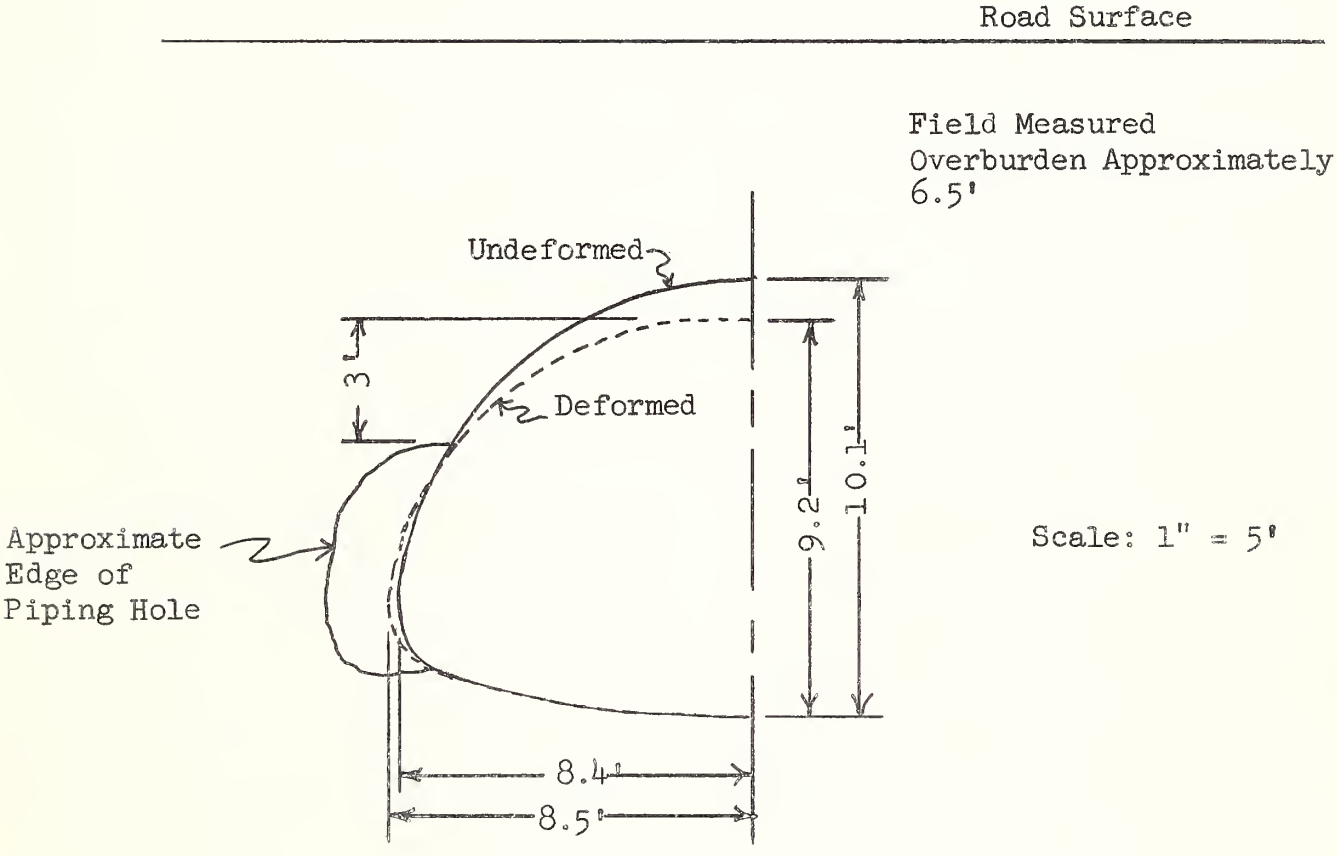


Figure 10. DEFORMED AND UNDEFORMED EMIGRANT CULVERT.

The measurements for the deformed shape are from cross sections located 44' (middle) and 60' from the inlet.

Also, the culvert was cantilevered at the outlet and the floor sagged downward. In other words, the outlet was undermined and the sagging was apparently due to lack of support under the sagged portion of the floor.

PIPING CHANNEL TRACED

Piping was in evidence during the first inspection because of the extensive undermining at the outlet and the water flowing from under the culvert. However, it was not until the second inspection, during the summer of 1964, that extensive piping along the left side of the culvert was discovered. Piping along the sides was not suspected during the initial Schmidt hammer survey because no criterion had yet been established for readings in three-gage culverts. Most of the previous Schmidt hammer readings had been taken in eight and ten-gage culverts. The open channel was found when holes were punched during the hole punch survey described in the preceding Chapter.

Figure 11 is a sketch showing the piping channel as traced by the hole punch survey.

It appears likely that water flowed under the culvert in the gravel foundation (noted from original construction notes), carrying away the finer particles, leaving voids. The backfill material along the left side was then free to sluff off or settle into the voids, with the finer material being continuously washed away, enlarging the hole along the side.

According to Arthur A. Anderson, Maintenance Foreman for the Emigrant area, the road surface has settled over the culvert several times and has been patched. Also, riprap has been dumped in near the outlet several times and, in the fall of 1963, the creek water was diverted and the inlet end stream bed and foundation were dug out several feet deep and about four feet back under the culvert. About three cubic yards of earth were packed into the dug-out hole. Also, rocks were hand placed under the under-

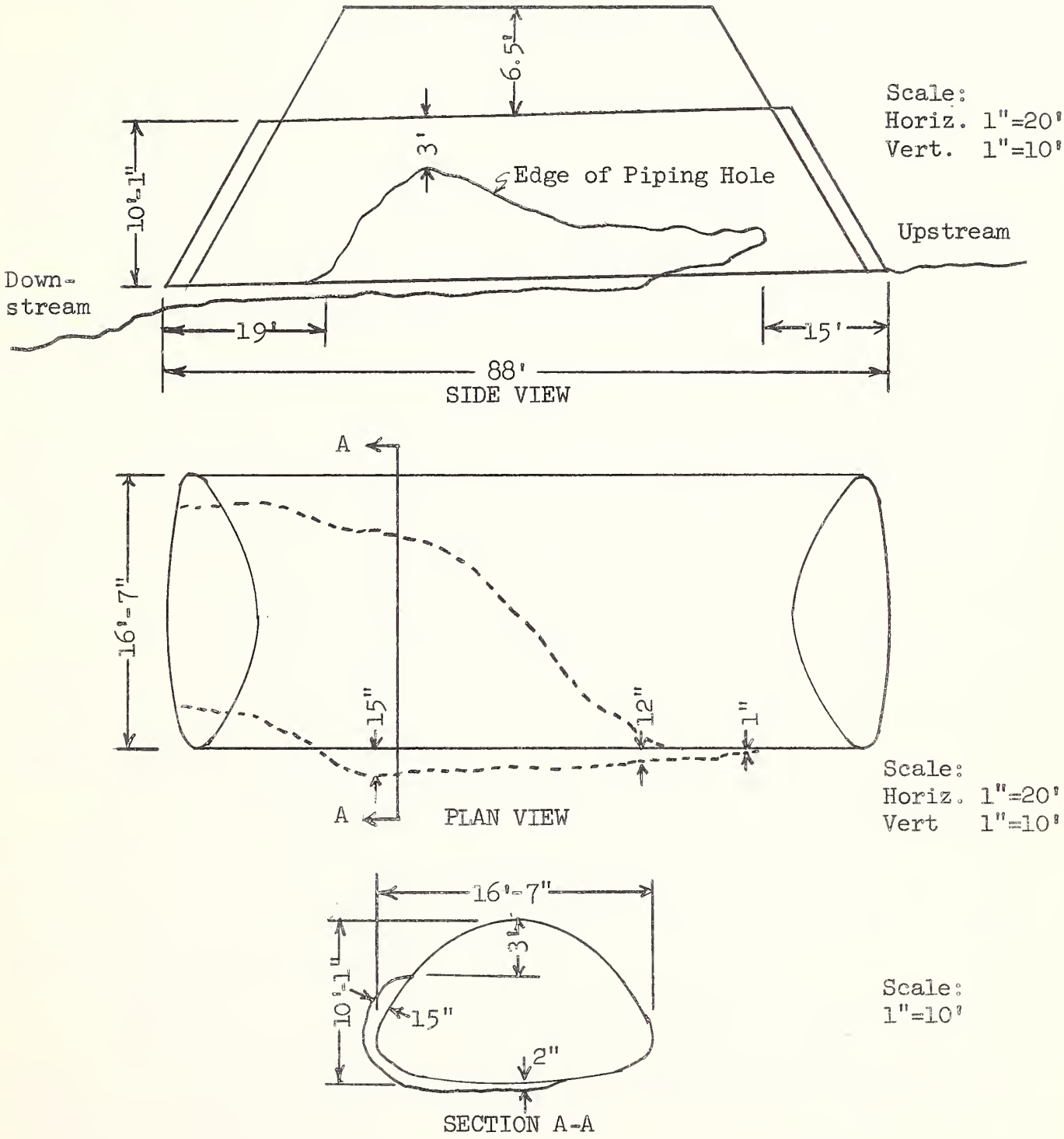


Figure 11. PIPING CHANNEL AT EMIGRANT CULVERT.

The floor was intermittently supported on gravel in the piping region shown. The left wall had one big void space behind it, varying in size similar to that shown above.

mined outlet at this time.

Inspection during the summer of 1964 showed that many of the hand placed rocks under the outlet had been washed away and water was flowing under the culvert.

MOMENT STRENGTH OF CULVERT SEAMS and MOMENT ANALYSIS OF EMIGRANT CULVERT

It was hypothesized that the failure of the Emigrant culvert, in the form of cracked plates along a longitudinal seam, was caused by bending moments in excess of the moment capacity of the seams. This hypothesis is given support by pictures in Michigan Engineering Experiment Station Bulletin 109, on pages 29 and 30, which show plate sections with bolted seams that were tested to failure by bending and exhibit cracks like those existing in the Emigrant culvert.

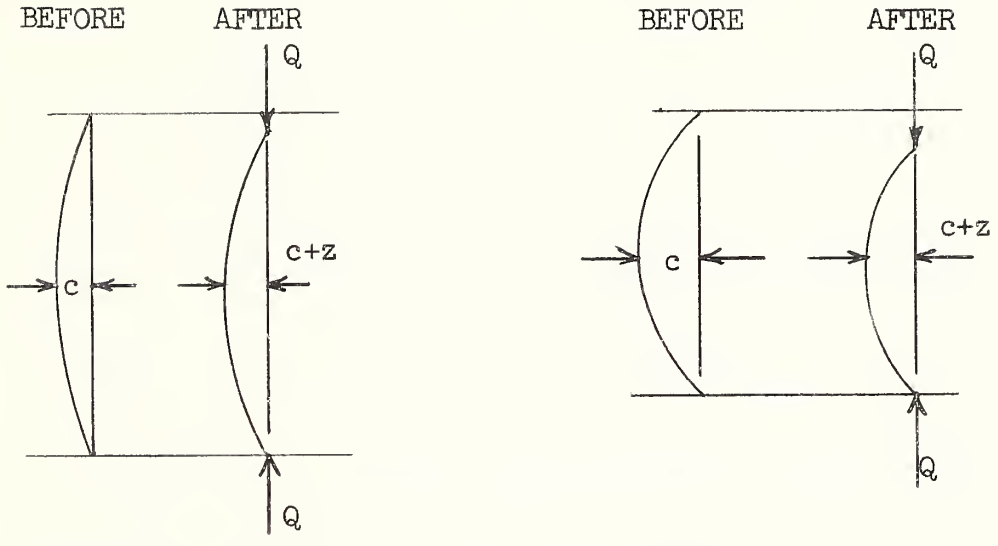
An investigation of the test data in Bulletin 109 to see what bending moments were developed at failure will now be presented.

Moment Strength of Culvert Seams

The information provided in Bulletin 109 that was used in this presentation pertains mainly to the single bolted sections of tests three, four, five and six. However, some reference is made to the tests on plain sections for comparison purposes.

Test three consisted of a column test on sections having a 150-inch radius. The only difference in test four was that 30-inch radius sections were tested (See Figure 12).

Tests five and six were simple beam tests where the specimens were supported at both ends and subjected to a downward force at the center. Test five consisted of 150-inch radius sections while test six had 50-inch



TEST 3
150" Radius Plates

TEST 4
30" Radius Plates

Figure 12. STANDARD STRUCTURAL CULVERT PLATES TESTED AS COLUMNS.

The sketches show the culvert sections before testing and the deflections at failure for tests three and four in Bulletin 109. z is the horizontal deflection corresponding to the peak load, Q.

radius sections (See Figure 13).

The moments developed at failure for test three and four, M_{max}, are equal to the ultimate load, Q, times (c + z). See Figure 12.

Table V is a tabulated summary of the analysis of data for tests three and four.

Table VI is a tabulated summary of the analysis of the data for tests five and six. The maximum moments for tests five and six are equal to one-half the ultimate load times the distance, d, at the time of failure (See Figure 13).

From the values in Tables V and VI, it can be seen that the bolted sections developed, for all practical purposes, the full moment capacity

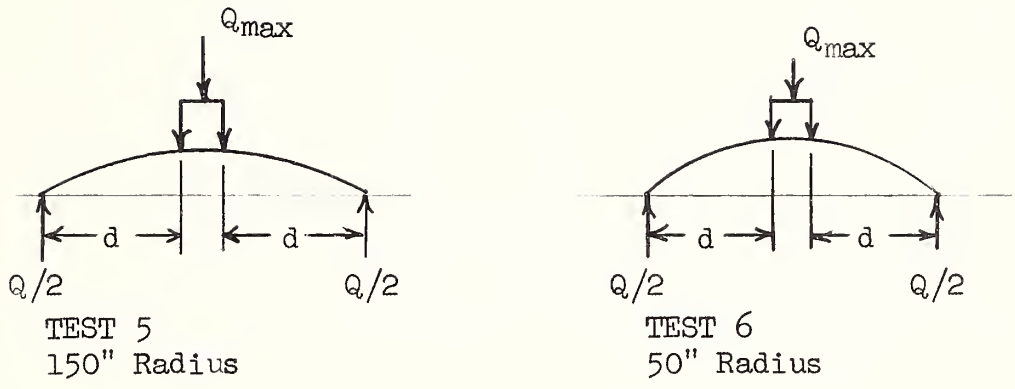


Figure 13. CULVERT PLATES TESTED AS SIMPLE BEAMS.

The sketch shows culvert sections as loaded in the simple beam tests, numbers five and six, in Bulletin 109.

of the unbolted plates.

Also of interest is that the plates of tests three and four, which were under considerable ring compression, P/A, during the bending, resisted bending moments of approximately the same magnitude as the plates of tests five and six, which were subjected to no ring compression.

From data shown in Tables V and VI, the plot of gage thickness versus failure moments gives the results as shown in Figure 14.

Of interest in this particular case study is the maximum moment that can be resisted by a standard three-gage culvert plate with a single bolted seam. By drawing a line that fits the points plotted in Figure 14, a value of 9,300 ft-lb/ft is indicated as the maximum bending moment possible for a three-gage section. This value will be referred to in a following section.

Moment Analysis of Emigrant Culvert

Referring back to Figure 11, very little lateral support was avail-

Table V. SUMMARY OF ANALYSIS OF DATA FOR COLUMN TESTS.

TEST	GAGE & BOLTED (B) OR PLAIN (P)	Q ULT. LOAD, KIPS	P ULT. LOAD, KIPS PER INCH	c INITIAL MOM. ARM, INCHES	z HORZ. DEF., AT PEAK LOAD, INCHES	x FINAL MOM. ARM, INCHES	M_{max} IN-K PER IN. OR FT-KIPS PER FT.	AREA* IN^2 PER IN.	$\frac{P}{A}$ KSI
3	1 B	52.3	2.38	2.29	1.42	3.71	8.8	.3432	6.9
	P	79.7	3.62	2.29	0.83	3.12	11.3		
	7 B	42.8	1.95	2.29	1.00	3.29	6.4	.2283	8.6
	P	48.6	2.21	2.29	0.94	3.23	7.1		
	12 B	28.2	1.28	2.29	1.04	3.33	4.3	.1297	9.8
	P	28.0	1.27	2.29	0.81	3.10	3.9		
4	1 B	21.0	0.955	11.05	1.16	12.21	11.7	.3432	2.8
	P	22.0	1.00	11.05	1.09	12.14	12.2		
	7 B	13.0	0.591	11.05	1.41	12.46	7.4	.2283	2.6
	P	12.0	0.545	11.05	0.98	12.03	6.6		
	12 B	7.0	0.318	11.05	0.93	11.98	3.8	.1297	2.4
	P	5.5	0.250	11.05	1.19	12.24	3.1		

*Areas taken from ARMCO's Handbook of Drainage and Construction Products

Table VI. SUMMARY OF ANALYSIS OF DATA FOR SIMPLE BEAM TESTS

TEST	GAGE & BOLTED (B) OR PLAIN (P)	Q ULT. LOAD, KIPS	P KIPS PER INCH	d AVE. ULT. MOMENT ARM, INCHES	$\frac{Pd}{2}$ MAX. MOMENT IN-LBS PER INCH
5	1 B	19.0	.864	24.25	10.5
	P	18.9	.860	24.25	10.4
	7 B	11.9	.541	24.25	6.6
	P	11.5	.523	24.25	6.3
	12 B	6.8	.309	24.25	3.7
	P	6.1	.277	24.25	3.4
6	1 B	18.0	.818	23.75	9.7
	P	22.0	1.000	23.75	11.9
	7 B	12.0	.546	23.75	6.5
	P	13.8	.627	23.75	7.4
	12 B	6.9	.313	23.75	3.7
	P	7.6	.345	23.75	4.1

able along the left side of the Emigrant culvert. A structural analysis of this culvert with no lateral support will be presented in order to demonstrate what bending moments might develop as a result of the vertical soil overburden load only.

Basic Mechanics

Consider the half-section of a culvert shown in Figure 15. If the loading is symmetrical, there will be no rotation at either A or B, and $\Delta\theta$, the rotation of the tangent at B with respect to the tangent at A will be equal to zero. Also, for symmetrical loading, the horizontal

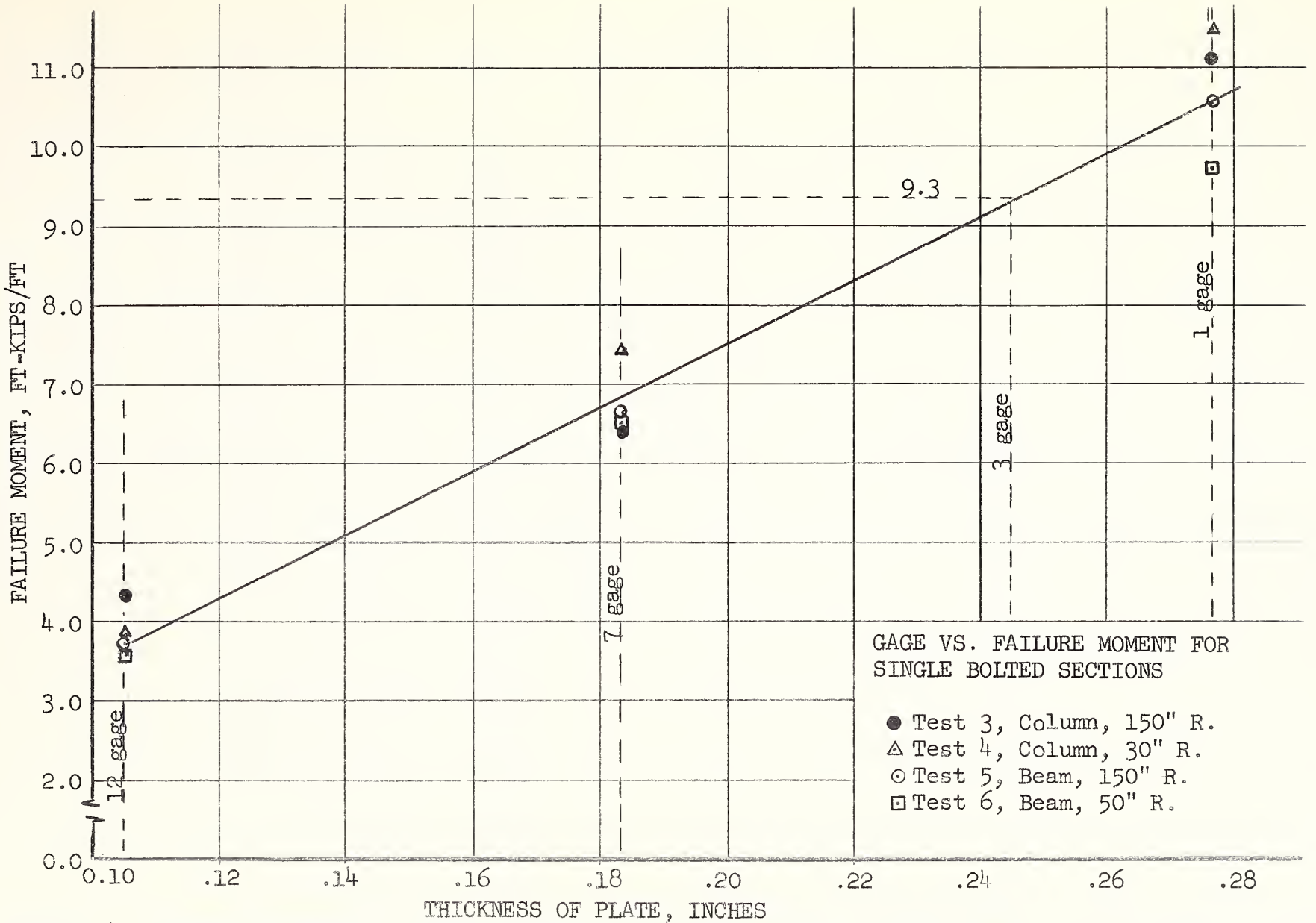


Figure 14. FAILURE MOMENTS FOR BOLTED STANDARD STRUCTURAL PLATE CULVERT SEAMS, AS CALCULATED FROM DATA GIVEN ON TEST SERIES 3, 4, 5 AND 6 IN THE MICHIGAN ENGINEERING EXPERIMENT STATION BULLETIN NO. 109.

deflection of both A and B is zero; therefore, Δx, the horizontal deflection of B with respect to A is equal to zero.

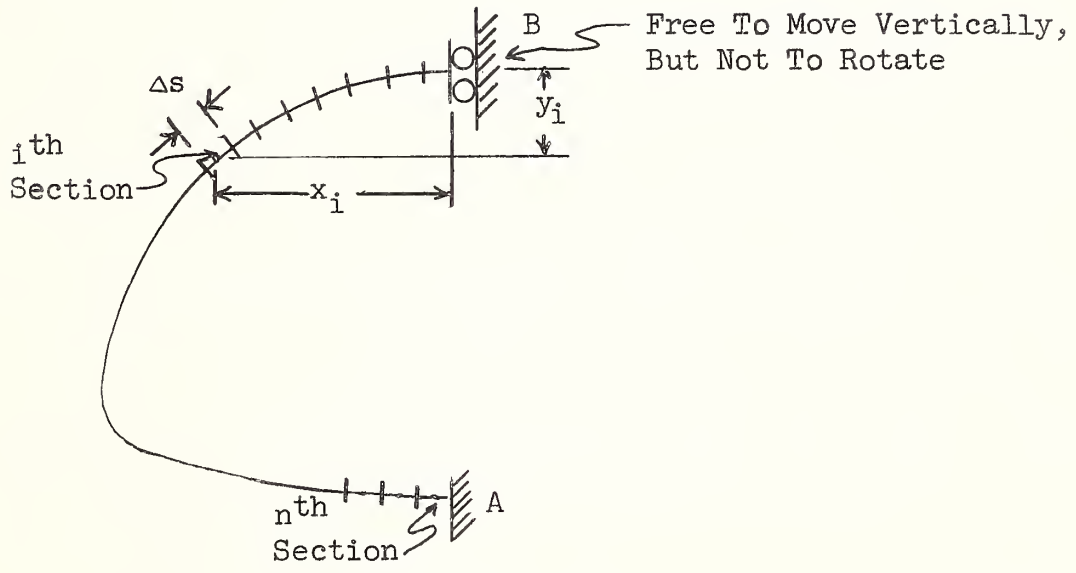


Figure 15. CULVERT HALF-SECTION.

The culvert half-section is divided into equal segments, Δs. The coordinates, x_i and y_i are shown for the i^{th} segment.

From well known structural theory, the following equations for $\Delta\theta$ and Δx are arrived at through a simple extension of the area-moment theorems. The equations are valid for the elastic range only, and only when deflections are primarily caused by bending.

$$\Delta\theta = \sum_{i=1}^{n} M_i \frac{\Delta s}{EI} = 0$$

$$\Delta x = \sum_{i=1}^{n} M_i y_i \frac{\Delta s}{EI} = 0$$

These equations have been written in terms of finite summations instead of integrals because it is much easier to solve them in this form in most practical situations. To conveniently make use of these equations, the half-culvert wall is first graphically divided up into a large number, n, of small segments of equal length, Δs, as indicated in Figure 15. The coordinates of the midpoint of each segment (measured from B) may then be scaled from the drawing. In Figure 15, x_i and y_i are the coordinates of the i^{th} segment. Referring to other terms in the equations, M_i is the bending moment at the center of the i^{th} segment, E is the modulus of elasticity of the culvert wall, and I is the centroidal moment of inertia of the wall cross section. In a culvert where plates of the same thickness are used all the way around the perimeter, both I and E will be constant. The entire expression $\frac{\Delta s}{EI}$ will then be the same for every segment, and the preceding equations will reduce to:

$$\sum_{i=1}^{n} M_i = 0 \qquad (1)$$

and

$$\sum_{i=1}^{n} M_i y_i = 0 \qquad (2)$$

For a given symmetrical loading, equations (1) and (2) may be used to solve for the bending moment, M_B, and the horizontal thrust, H_B, at the top point, B. Having these, the bending moment at any point may then be calculated. This will be illustrated below for the use of uniform loading (the same pressure, p, acting vertically and laterally).

Figure 16 shows a free-body diagram of part of the culvert wall when point D is taken as the midpoint of the i^{th} segment.

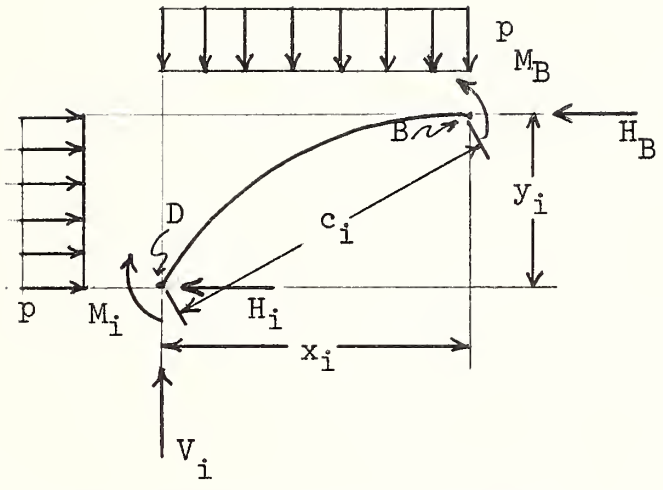


Figure 16. FREE-BODY DIAGRAM OF PART OF CULVERT WALL.

From statics we may write that the sum of the moments about point D is equal to zero and solve for M_i in terms of M_B and H_B as follows:

$$\sum M_D = 0$$

$$M_i + \frac{p\, y_i^2}{2} + \frac{p\, x_i^2}{2} - M_B - H_B y_i = 0$$

$$M_i = M_B + H_B y_i + \frac{p}{2}\,(y_i^2 + x_i^2)$$

Next substituting $(y_i^2 + x_i^2) = c_i^2$, where c_i is the length of the chord from B to D, we get:

$$M_i = M_B + H_B y_i - \frac{p}{2} c_i^2 \qquad (3)$$

Computer Program

With the use of the foregoing equations, a Fortran computer program for finding the bending moments at any section in a culvert wall was developed for use in an IBM 1620. This program was developed for "p"

loading (equal vertical and lateral pressures).

The input data required for the computer program is: the number of sections, n, into which the half-culvert is divided, the uniform pressure, p, on the culvert, and the coordinates x_i, y_i, and c_i.

Another program, similar to the one above, was used to solve for bending moments with uniform lateral loading only, of pressure q. By subtracting the bending moments computed for "q" loading from those calculated for "p" loading, the bending moments for vertical loading with no lateral support are obtained, if q is considered equal to p.

Besides the loading of interest in this study, the programs permit one to easily calculate moments for a loading situation wherein the lateral pressure is equal to any desired percentage of the vertical pressure. For example, the moments for a situation where the lateral pressure is equal to two-thirds of the vertical pressure may be obtained by setting q equal to one-third p and subtracting the moments for this situation from the "p" load moments.

These programs, along with input and output data and a worked out example, are presented in Appendix C.

Results of Analysis of the Emigrant Culvert

Figure 17 shows a typical cross section of the Emigrant culvert with the loading approximated by a 935 psf average overburden pressure, and zero lateral pressure, which corresponds approximately to the overburden situation when the culvert was surveyed in the summers of 1963 and 1964. The total volume of earth over the culvert would result in a depth of about eight and one-half feet if spread out evenly.

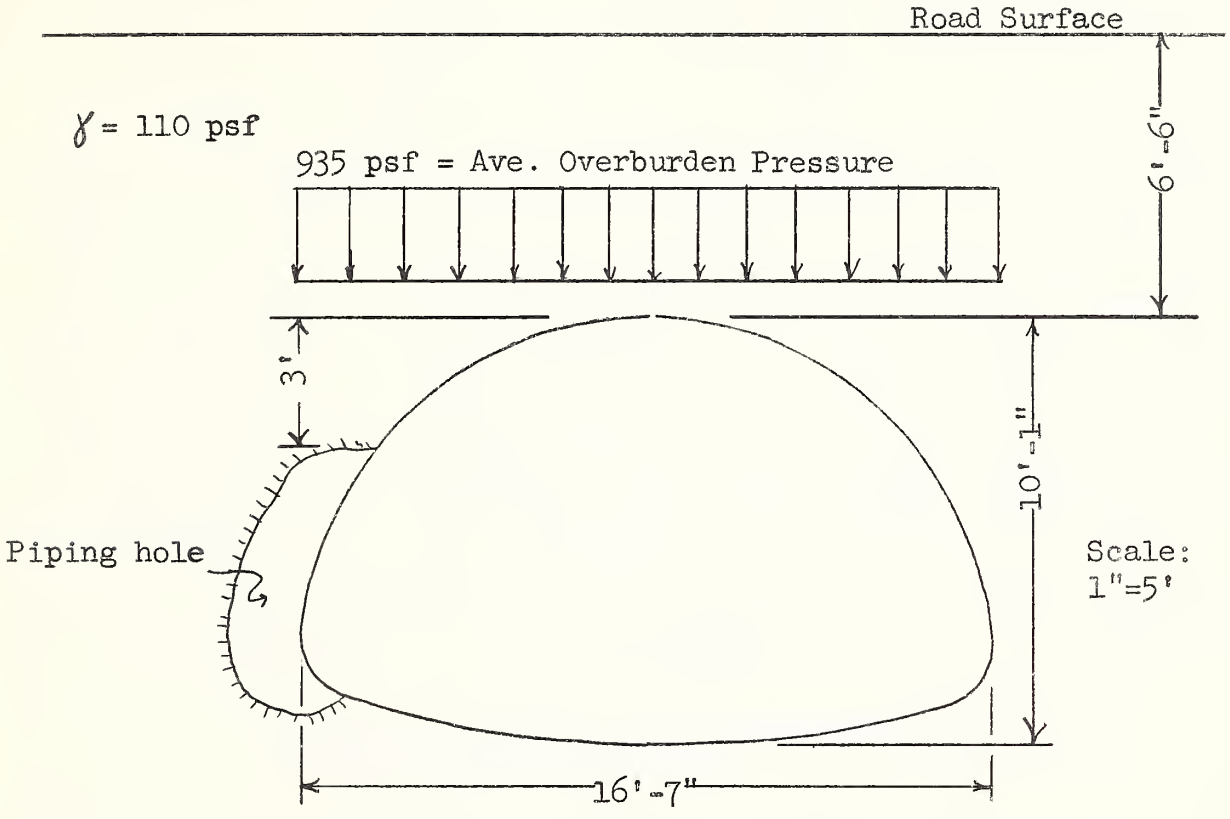


Figure 17. TYPICAL CROSS SECTION OF THE EMIGRANT CULVERT.

The figure shows the overburden and the approximated pressure on the Emigrant culvert.

Using the undeformed shape of the culvert, the theoretical moment diagram for an average vertical pressure of (8.5)(110) = 935 psf is shown in Figure 18(a).

Using the deformed culvert shape, as it existed at the time of this research, the theoretical moment diagram is that shown in Figure 18(b). A comparison of the two moment diagrams shows that in this case, calculated theoretical moments are in error by as much as 12 percent at section 13, if the culvert deformation is neglected.

The tables of bending moments from which the moment diagrams were plotted are given in Appendix C.

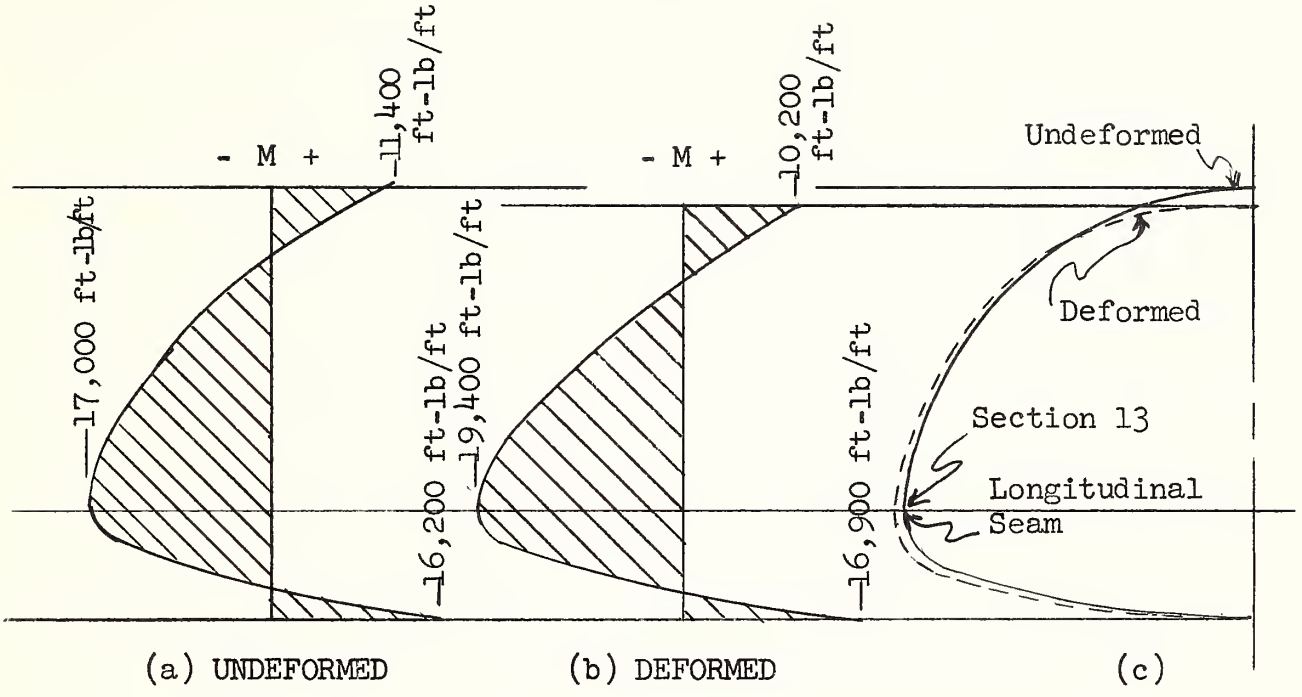


Figure 18. MOMENT DIAGRAM FOR UNDEFORMED AND DEFORMED EMIGRANT CULVERT.

The diagrams represent the bending moments for the Emigrant culvert with a vertical pressure of 935 psf and no lateral pressure.

As can be seen in Figure 14, the maximum moment possible on this type seam as determined from data in the report of the Michigan Experiment Station test, for three-gage plates is 9,300 ft-lbs per foot of seam. If 9,300 ft-lb/ft is the maximum moment possible, then those calculated for the deformed Emigrant culvert (Figure 18(b)) indicate that the culvert plates were stressed into the plastic range in several places. In fact, the cracked plates are evidence that the upper limit of the plastic range was exceeded at section 13 and the cracks resulted, forming a hinge along the seam. With a hinge along this longitudinal seam, the moments at the top and bottom of the culvert section will, without doubt, reach their maximum "plastic" values. In other words, a plastic hinge will develop at both B and A. This is a logical assumption since there was no evi-

dence of seam damage at the top or bottom of the culvert.

The fact that the culvert is still standing constitutes evidence that there is some lateral support acting, and the assumption that the culvert is subjected to zero lateral pressure is too severe. Using a typical one-foot long section from the region of the large piping hole did not take into consideration the lateral support provided the culvert near the ends. Also, there is lateral support above the piping hole. However, neglecting the lateral support is compensated for, to some degree, by the fact that vehicle loads were neglected also.

To get an idea of how much lateral support would be necessary to keep the bending moments, computed under the assumption of the foregoing analysis, within the maximum 9,300 ft-lb/ft, consider the output data given in Appendix C for the undeformed Emigrant culvert with uniform pressure, p, acting vertically and horizontally. The maximum coefficient, at section 13, is -13.8. Multiplying -13.8 by 935 psf, a moment of -12,900 ft-lb/ft is obtained. This is a reduction of 24 percent in the bending moment at section 13, but is still in excess of the maximum possible moment of 9,300 ft-lb/ft.

In a properly installed flexible culvert, the lateral pressure may actually be larger than the vertical pressure, but, assuming the initial pressures were the same in this case, there is an indication that the culvert could have been stressed into the failure range before piping removed the lateral support. However, it is reasonable to say that loss of lateral support adds to the danger of excessive stresses due to larger bending moments.

CHAPTER VI

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

DISCUSSION

The problem of piping has to be regarded as a serious one, not only because of the cost of repairs or replacement of a completely washed-out culvert, but also because of the possible dangers to unsuspecting motorists, if the road surface should collapse into a piping channel.

In the case of the Cardwell culvert and the Okeefe Creek culverts, the piping was to such an advanced stage that there was a possibility of the fill over the void collapsing, making a break in the road surface. Collapsing of the fill was in evidence at the inlet side of the Okeefe culverts on the sloping portion of the fill between the culverts (See Figure 5).

In several cases, the soil apparently was arching over piping holes and appeared to be safe. However, with a piping channel already formed, high water could easily erode the fill to such a degree that the arching soil would collapse.

There is also the possibility that the loss of lateral support due to piping may lead to cracked plates and possibly complete structural collapse. A seam with cracked plates can carry very little, if any, bending moment and acts as a hinge. After a hinge has formed, other portions of the culvert, mainly longitudinal seams at the center top and bottom, can be stressed above allowable limits, leading to a collapse.

In the Emigrant culvert the longitudinal seams ran in a straight line the full length of the culvert. In some culverts the longitudinal seams are off-set from one plate to the next. Cracked plates in this type of cul-

vert were seen in at least two Large Culvert Research Project installations, Numbers 7 and 44. The cracks followed the seams from one plate to the next even though they were not in a straight line. As was pointed out in the case study in Chapter V, the seams, for all practical purposes, can resist moments of the same magnitude as the plain section. Why is it then, that the cracked plates follow the seams of one section to the off-set seam of the next section?

A possible explanation is that excessive stress concentrations develop at the edges of the bolt holes, these stresses being of a higher value than those that develop anywhere else in the plates. In other words, the bolt holes are the weak spots in the plates and cracking will occur here before anywhere else.

Some comments can be made about the existence of piping and how to find it. The only sure methods found in this study for the determination of piping around culverts are visual observation of piping holes at the ends of the culvert and tracing a piping hole by punching holes in the culvert wall.

The results of the hole punch and Schmidt hammer survey indicate that the Schmidt hammer is useful for determining the fill condition, but no exact correlation between Schmidt hammer readings and the fill condition were evident. However, when the variables involved are taken into consideration, the Schmidt hammer can supplement an investigation of the backfill.

During the hole punch survey, many cases of extremely soft, wet, fill behind the culverts were found. An eighth-inch diameter wire, that was used for probing through a punched hole, could easily be pushed into the fill,

sometimes as much as two feet. The backfill was certainly not placed in this wet condition, so the water must have infiltrated from outside sources. This leads to the question of what effects this water may have on the backfill. Some soils swell excessively when wetted and pressures due to the swelling may be harmful to the culvert. Also, it seems logical that the fill next to a culvert could freeze during winter. Ice lenses could form, causing harmful pressures. There is also the possibility that when the ice lenses melt, voids will be left, making an ideal weakness zone for seepage to occur.

With regard to soil types, piping was found to have developed in a wide range of soils. Although a cohesionless sand or silt would be expected to be more susceptible to piping than a cohesive soil, full consideration should be given to the prevention of piping during design and construction with any soil.

CONCLUSIONS

In view of the foregoing discussion and study, the following conclusions were reached:

1) Piping removes backfill from around a culvert and, in some cases, causes an excessive loss of lateral support. (There is a possibility the loading situation that develops under these conditions may cause excessive bending moments which stress the culvert plates to the failure limit.)

2) The Schmidt hammer is a useful tool for helping to determine the fill condition behind culvert plates.

3) Piping occurs in a wide variety of soil types, including sand, silt and clay.

RECOMMENDATIONS

Due regard should be given to the problem of piping in the design

and construction of culverts. There is no way of determining the exact cause of piping, but the following factors may influence the development of piping and can be considered in either design or construction.

Degree of Compaction for Culvert Bedding and Backfill

As pointed out in the Literature Search, the proper degree of compaction should be specified. Then, close inspection should be employed during construction to see that the specifications are carried out.

Headwalls

Headwalls, both at the inlet and outlet are now standard practice by the Montana Highway Department. The minimum depth from the invert to the bottom of the headwall is three feet. It is recommended that where exceptionally erodible soil is used for backfill, the headwall should be extended downward for a greater depth. This would help prevent undermining at the outlet and would lengthen the seepage paths of the water at both ends, which helps dissipate the energy of the water. Headwalls might also extend higher, as the piping hole at the Cardwell culvert was above the standard headwall height.

Controlled Seepage

When the bedding and backfill material around the culvert is such that excessive seepage will occur, controls such as outlet drains and reverse filters can help prevent the finer material from being eroded away.

Outlet drains can be placed under the outlet invert, collecting the seepage water before it reaches the surface of the fill and dispensing with it in a safe way.

Reverse filters are placed such that the finer material is placed

nearest the fill being protected, with increasingly coarser material being placed over finer material. The fine material of the fill is then prevented from eroding away by the trapping action of the filters.

Culvert Size

Normal flow through a culvert will usually not be enough to back water up at the inlet, creating a head. When water is backed up at the inlet, seepage pressures may become large enough to cause piping at a site which would normally be safe from piping. This suggests that it might be wise to guard against allowing large heads to develop, in some cases, by specifying a larger culvert.

Culvert Bedding

It is very important that the culvert plates fit firmly on the culvert bedding, as a loose fit will leave an ideal place for excessive seepage and, eventually, piping to develop. Possibly a template with the shape of the culvert could be used in preparing the culvert bed. Then, after all the bottom culvert plates are in place, the entire floor could be pulled a few inches, either upstream or downstream, to fill the corrugations with the bedding material (See Figure 19).

A tractor or winch could be used for pulling on smaller installations, but this would not be possible with larger pipes.

Watertight Joints

If the joints of a culvert are not watertight, seepage may occur through the joints, with water entering the fill under high pressure through leaky joints near the outlet. This pressure may be enough to erode the material around the culvert and create an open channel. Therefore, it would

be desirable if all joints were properly sealed and watertight so that seepage water would be forced to seep through the soil for the full length of the culvert so that most of its energy is dissipated before it reaches the critical outlet region.

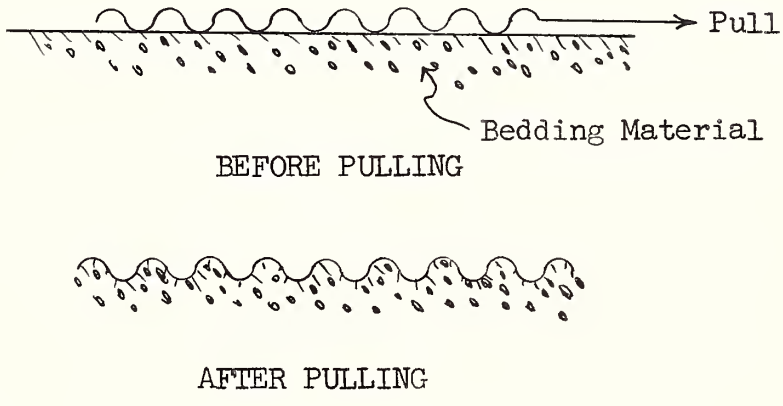


Figure 19. CROSS SECTIONS OF CORRUGATIONS ON BEDDING.

The figure shows the bedding material with respect to the corrugations before and after pulling a culvert floor.

Cutoff Diaphrams

Cutoff diaphrams around the culvert located at intervals along the length of the culvert would intercept water seeping close to the culvert. The seepage water would either be stopped or the seepage paths would be lengthened, dissipating the energy of the water. Diaphrams, made either of metal or concrete, may be practical at some installations and should be considered as a possibility in controlling seepage water.

Recommendations for Future Study

As pointed out in Chapter IV, one of the shortcomings of the

Schmidt hammer was the shape of the plunger head. The face of the plunger has about the same curvature as the surface the readings were taken on. In some instances, upon repeated readings, the numerical readings would increase as the surface roughness in the zinc coating was flattened out.

It is therefore recommended that plungers with different shaped faces be tried to see if the variations can be eliminated, or at least reduced.

APPENDICES

APPENDIX A

MECHANICAL ANALYSIS

MECHANICAL ANALYSIS OF SAMPLES FROM PIPING HOLES

SOIL SAMPLE FROM	PERCENT PASSING OR SMALLER THAN									
	3/8"	#4	#10	#40	#100	#200	.05 mm.	.01 mm.	.005 mm.	.002 mm.
Emigrant	74.4	67.2	56.5	38.1	22.6	12.4	9.0	5.5	4.1	2.4
Cardwell	100.0	100.0	100.0	99.3	98.0	92.0	72.3	21.0	15.2	11.5
Okeefe	98.7	97.9	97.7	95.3	92.8	91.0	87.1	77.3	68.0	41.2
Chester	100.0	98.5	97.9	92.5	80.0	63.6	57.0	35.2	27.0	19.1
Wolf Point No. 1	100.0	100.0	100.0	99.4	94.0	84.5	75.8	41.1	36.0	28.9
Wolf Point No. 2	96.7	95.7	95.2	93.0	83.0	73.4	65.5	43.8	36.0	29.1

APPENDIX B

HOLE PUNCH DATA

HOLE PUNCH DATA TABULATIONS FOR THE LARGE CULVERT PROJECT

10-GAGE PIPE-ARCH

	REGION READINGS WERE TAKEN								
	WALL			18" RADIUS			FLOOR		
	EMPTY	SOFT	FIRM	EMPTY	SOFT	FIRM	EMPTY	SOFT	FIRM
	32	34	40	24	38	40	24	28	35
	30	36	40	26	40	40	26	30	38
			41	34	38	44	22	33	
				34	42	44			
				34	40	50			
				30	42				
					40				
					38				
					36				
AVE.	31	35	40	30	39	44	24	30	37

The numbers in the table are Schmidt hammer readings taken at points where holes were punched to determine the fill condition.

10-GAGE CIRCULAR

READINGS FROM BOTTOM HALF OF CULVERT			
	EMPTY	SOFT	FIRM
	26 READINGS TAKEN	66 READINGS TAKEN	22 READINGS TAKEN
RANGE	25 ± 2	29 ± 4	38 ± 8

Too many Schmidt hammer readings were taken to list singly, therefore, the number of readings that were taken are noted along with the ranges which include at least 80 percent of the readings.

8-GAGE PIPE-ARCH

REGION READINGS WERE TAKEN								
WALL			18" RADIUS			FLOOR		
EMPTY	SOFT	FIRM	EMPTY	SOFT	FIRM	EMPTY	SOFT	FIRM
	38	43	40	46	50	36	32	40
	35	40	40	46	50	34	34	
	38	40	40	44	50	32	38	
	40	42	40	38	50	28	30	
	42	42	42	48	50	30	30	
	40	42		44	48	34	38	
	38			40	50	34		
	40			45	52	30		
	40			40	48	36		
	42			46	48			
	44			44				
	40			46				
				46				
				44				
				42				
				42				
				42				
AVE.		40	42	40	44	50	33	34	40

The numbers in the table are Schmidt hammer readings taken at points where holes were punched to determine the fill condition.

3-GAGE PIPE-ARCH

	REGION READINGS WERE TAKEN								
	WALL			18" RADIUS			FLOOR		
	EMPTY	SOFT	FIRM	EMPTY	SOFT	FIRM	EMPTY	SOFT	FIRM
	40	40	44	40	46	52	38		44
	44	40	45	40	44	50	42		48
	42	40	48	42	44	48	40		44
	40	44	46	42	42		38		48
	40		46	39	44				
	41		48	42					
			46	40					
AVE.	41	41	46	41	44	50	40		46

The numbers in the table are Schmidt hammer readings taken at points where holes were punched to determine the fill condition.

APPENDIX C

COMPUTER PROGRAMS AND INPUT AND OUTPUT DATA

FORTRAN COMPUTER PROGRAMS FOR DETERMINING THE BENDING MOMENTS AT ANY POINT IN A CULVERT

Program 1: For equal vertical and lateral pressures, "p" loading.

```
C  C
C     STRUCTURAL ANALYSIS OF CULVERTS WITH UNIFORM LOADING
C         FOR LARGE CULVERT PROJECT
      READ 100,N
  100 FORMAT  (13)
      READ 101,P
  101 FORMAT (F10.5)
      DIMENSION X(200),Y(200),C(200)
      DO 20 I=1,N
   20 READ 102,X(I),Y(I),C(I)
  102 FORMAT (3F10.3)
      CSQ=0.
      YSQ=0.
      CSQY=0.
      SUMY=0.
      PUNCH 105,P.
  105 FORMAT (5H P = ,F10.5//)
  104 FORMAT (47H  SECTION                  COEF.              MOMENT    ///)
      FN=N
      DO 21 I=1,N
      CSQ=CSQ+C(I)**2./2.
      YSQ=YSQ+Y(I)**2.
      CSQY=CSQY+Y(I)*C(I)**2./2.
   21 SUMY=SUMY+Y(I)
      H=(CSQ/FN-CSQY/SUMY)/(SUMY/FN-YSQ/SUMY)
      FMT=CSQ/FN-H*SUMY/FN
  114 FORMAT  (43H SUM Y         C SQ/2        MOM TOP     H/)
  115 FORMAT(2F10.2,5X,F10.3,5X,F10.3///)
      PUNCH  114
      PUNCH  115,SUMY,CSQ,FMT,H
      PUNCH 104
      DO 22 I=1,N
      COE=FMT+H*Y(I)-C(I)**2./2.
      FMOM=COE*P
   22 PUNCH 103,I,COE,FMOM
  103 FORMAT (4X,13,10X,F10.5,11X,F10.5)
      STOP
      END
```

Program 2: For lateral pressures "q" only.

```
C  C
C     DATA CARDS FOR PROGRAM 1 CAN BE USED
C     MOMENT AT ANY SECTION DUE TO LATERAL LOADING
      READ  100,N
  100 FORMAT(I3)
      READ 101,Q
  101 FORMAT(F10.5)
      DIMENSION Y(200)
      DO 20 I=1,N
   20 READ 102,Y(I)
  102 FORMAT(9XF10.3)
      YSQ=0.
      YCU=0.
      SUMY=0.
      PUNCH 105,Q
  105 FORMAT(5H Q = ,F10.5//)
  104 FORMAT (47H  SECTION           COEF.            MOMENT    ///)
      FN=N
      DO 21 I=1,N
      YSQ=YSQ+Y(I)**2.
      YCU=YCU+Y(I)**3./2.
   21 SUMY=SUMY+Y(I)
      H=(YCU-SUMY*YSQ/(FN*2.))/(YSQ-SUMY**2./FN)
      FMT=YSQ/(FN*2.)-H*SUMY/FN
  114 FORMAT (43H SUM Y         Y SQ            MOM TOP      H/)
  115 FORMAT(2F10.2,5X,F10.3,5X,F10.3//)
      PUNCH 114
      PUNCH 115,SUMY,YSQ,FMT,H
      PUNCH 104
      DO 22 I=1,N
      COE=FMT+H*Y(I)-Y(I)**2./2.
      FMOM=COE*Q
   22 PUNCH 103,I,COE,FMOM
  103 FORMAT (4X,I3,10X,F10.5,11X,F10.5)
      STOP
      END
```

COMPUTER PROGRAM INPUT DATA FOR THE DEFORMED EMIGRANT CULVERT

n = 22
p or q = 0.0

x	y	c	SECTION
.47	.05	.47	1
1.40	.25	1.42	2
2.30	.55	2.35	3
3.15	.95	3.30	4
3.95	1.41	4.20	5
4.75	1.95	5.15	6
5.50	2.00	6.07	7
6.25	3.10	7.00	8
6.90	3.75	7.88	9
7.47	4.50	8.75	10
7.98	5.30	9.60	11
8.35	6.15	10.40	12
8.50	7.00	11.05	13
8.10	7.85	11.32	14
7.20	8.38	11.10	15
6.20	8.60	10.65	16
5.20	8.78	10.24	17
4.25	8.92	9.90	18
3.32	9.00	9.58	19
2.35	9.05	9.35	20
1.42	9.15	9.25	21
.47	9.18	9.18	22

COMPUTER PROGRAM INPUT DATA FOR THE UNDEFORMED EMIGRANT CULVERT

n = 22

p or q = 0.0

x	y	c	SECTION
0.50	0.01	0.50	1
1.50	0.12	1.50	2
2.47	0.38	2.50	3
3.40	0.72	3.45	4
4.29	1.18	4.42	5
5.10	1.47	5.38	6
5.84	2.39	6.30	7
6.51	3.13	7.20	8
7.09	3.95	8.11	9
7.56	4.85	8.98	10
7.92	5.78	9.80	11
8.18	6.75	10.60	12
8.30	7.75	11.34	13
7.96	8.66	11.78	14
7.12	9.17	11.60	15
6.15	9.41	11.24	16
5.19	9.60	10.90	17
4.26	9.78	10.65	18
3.31	9.90	10.44	19
2.38	10.00	10.28	20
1.45	10.08	10.20	21
0.50	10.12	10.12	22

The proper format, as indicated in the computer programs, must be followed when the input data is punched on the computer input cards. The above data is not in the exact format because of the margin restrictions and because of the effort made to clarify the data.

OUTPUT DATA FOR UNDEFORMED EMIGRANT CULVERT WITH "p" LOADING

p = 0.0

SUM Y	C SQ/2	MOM TOP	H
125.2	848.5	5.7	5.8

SECTION	COEF.	MOMENT
1	5.6	0.0
2	5.2	0.0
3	4.7	0.0
4	3.9	0.0
5	2.7	0.0
6	-.3	0.0
7	-.4	0.0
8	-2.2	0.0
9	-4.4	0.0
10	-6.6	0.0
11	-8.9	0.0
12	-11.5	0.0
13	-13.8	0.0
14	-13.7	0.0
15	-8.6	0.0
16	-3.1	0.0
17	1.8	0.0
18	5.5	0.0
19	8.4	0.0
20	10.6	0.0
21	11.9	0.0
22	13.0	0.0

OUTPUT DATA FOR UNDEFORMED EMIGRANT CULVERT WITH "q" LOADING

q = 0.0

SUM Y	Y SQ	MOM TOP	H
125.2	1035.4	-6.5	5.3

SECTION	COEF.	MOMENT
1	-6.4	0.0
2	-5.8	0.0
3	-4.5	0.0
4	-2.9	0.0
5	-.9	0.0
6	.2	0.0
7	3.3	0.0
8	5.1	0.0
9	6.6	0.0
10	7.3	0.0
11	7.3	0.0
12	6.3	0.0
13	4.4	0.0
14	1.7	0.0
15	-.2	0.0
16	-1.1	0.0
17	-1.9	0.0
18	-2.7	0.0
19	-3.3	0.0
20	-3.8	0.0
21	-4.1	0.0
22	-4.3	0.0

OUTPUT DATA FOR DEFORMED EMIGRANT CULVERT WITH "p" LOADING

p = 0.0

SUM Y	C SQ/2	MOM TOP	H
116.1	763.7	4.7	5.7

SECTION	COEF.	MOMENT
1	4.9	0.0
2	5.1	0.0
3	5.1	0.0
4	4.7	0.0
5	3.9	0.0
6	2.6	0.0
7	.6	0.0
8	-2.0	0.0
9	-5.0	0.0
10	-8.0	0.0
11	-11.4	0.0
12	-14.8	0.0
13	-17.2	0.0
14	-15.4	0.0
15	-8.9	0.0
16	-3.1	0.0
17	2.4	0.0
18	5.7	0.0
19	10.1	0.0
20	12.4	0.0
21	13.8	0.0
22	14.6	0.0

OUTPUT DATA FOR DEFORMED EMIGRANT CULVERT WITH "q" LOADING

p = 0.0

SUMY	Y SQ	MOM TOP	H
116.1	861.0	-6.2	4.9

SECTION	COEF.	MOMENT
1	-6.0	0.0
2	-5.0	0.0
3	-3.7	0.0
4	-2.0	0.0
5	-.4	0.0
6	1.4	0.0
7	2.9	0.0
8	4.1	0.0
9	5.1	0.0
10	5.6	0.0
11	5.6	0.0
12	5.0	0.0
13	3.5	0.0
14	1.3	0.0
15	-.3	0.0
16	-1.1	0.0
17	-1.8	0.0
18	-1.9	0.0
19	-2.6	0.0
20	-2.9	0.0
21	-3.2	0.0
22	-3.5	0.0

SAMPLE MOMENT CALCULATION FROM COMPUTER OUTPUT DATA

From the output data shown on the previous two pages, the bending moment in ft-lbs/ft, at any section may be obtained by merely multiplying the coefficient (from column two in the output data) by the numerical value of p or q, in psf.

As an example, the bending moment for section number three will be computed for the deformed Emigrant culvert with no lateral support. This requires using the output from both programs. As explained earlier "p" loading is for equal pressure, both vertically and horizontally, and the "q" loading is a lateral pressure only.

By taking the coefficient for section three with "p" loading (5.1) and subtracting from it, algebraically, the coefficient for section three with "q" loading (-3.7), the coefficient obtained is 8.8. Multiplying the coefficient 8.8 by the desired pressure, say p = q = 935 lb per sq ft, the bending moment at section three is found to be 8,200 ft-lb per ft of width. This is the bending moment for vertical loading only. This is an example of how the entries in the bending moment tables on the next two pages were calculated.

If numerical values for "p" and "q" had been assigned in the input data for the computer program, the moments for each section in column three of the output data would have been given instead of all the zeros under the heading "MOMENT".

CALCULATIONS FOR FINDING THE BENDING MOMENTS PLOTTED IN FIGURE 18(b), PAGE 40, FOR THE DEFORMED EMIGRANT CULVERT WITH ESTIMATED VERTICAL PRESSURE OF 935 PSF.

p = 935 psf

SECTION	p COEF.	q COEF.	p COEF.-q COEF.	MOMENT AT ANY SECTION (p COEF.-q COEF.) p, ft-lb/ft
Top	4.7	-6.2	10.9	10,200
3	5.1	-3.7	8.8	8,200
5	3.9	-0.4	4.3	4,000
7	0.6	2.9	-2.3	-2,200
9	-5.1	5.1	-10.2	-9,500
11	-11.4	5.6	-17.0	-15,900
13	-17.2	3.5	-20.7	-19,400
15	-8.9	-0.3	-8.6	-8,000
17	2.4	-1.8	4.2	3,900
19	10.1	-2.6	12.7	11,900
22	14.6	-3.5	18.1	16,900

The p Coef. and q Coef. were obtained from the computer output shown on pages 63 and 64.

CALCULATIONS FOR FINDING THE BENDING MOMENTS PLOTTED IN FIGURE 18(a), PAGE 40, FOR THE UNDEFORMED EMIGRANT CULVERT WITH ESTIMATED VERTICAL PRESSURE OF 935 PSF.

p = 935 psf

SECTION	p COEF.	q COEF.	p COEF.-q COEF.	MOMENT AT ANY SECTION (p COEF.-q COEF.) p, ft-lb/ft
Top	5.7	-6.5	12.2	11,400
3	4.7	-4.5	9.0	8,400
5	2.7	-0.9	3.6	3,400
7	-0.4	3.3	-3.7	-3,500
9	-4.4	6.6	-10.9	-10,200
11	-8.9	7.3	-16.7	-15,600
13	-13.8	4.4	-18.2	-17,000
15	-8.6	-0.2	-8.4	-7,900
17	1.8	-1.9	3.7	3,500
19	8.4	-3.3	11.7	10,900
22	13.0	-4.3	17.3	16,200

The p Coef. and q Coef. were obtained from the computer output shown on pages 61 and 62.

APPENDIX D

SUMMARY OF CULVERT SURVEY FINDINGS FOR THE LARGE CULVERT RESEARCH PROJECT

CULVERT DESCRIPTION & LOCATION FOR LARGE CULVERT RESEARCH PROJECT

CULVERT NO.	GAGE	TYPE	SIZE, FEET	HIGHWAY NO., PROJECT NO. AND STATION	COUNTY	CREEK NAME	DESCRIPTION OF LOCATION	MANUFACTURER OF CULVERT PLATES
1	3	SPPA	16.58 x 10.08	89 Alt. F 217(10), 785 + 00	Park	Eightmile	3.5 mi. N. of Emigrant	U.S. Steel
2	10	SPPE	7.5	376, S 187(2), 2101 + 20	Blaine		13.5 mi. S. of U.S. 2	ARMCO
3	---	RCP	9.0	359, S 167(6), 121 + 41	Madison	Little Antelope	11.6 mi. S. of Jefferson Island	
4	---	RCP	9.0	359, S 167(6), 195 + 46	Madison	Antelope	10.0 mi. S. of Jefferson Island	
5	10	SPPE	7.25	395, S 167(5), 473 + 45	Madison		4.4 mi. S. of Jefferson Island	ARMCO
6	10	SPPE	9.0	359, S 167(3), 133 + 00	Madison		1.1 mi. S. of Jefferson Island	ARMCO
7	10	SPPC	11.0	SSG 156(1)U1 23 + 60	Silver Bow		Victor Chem. Plant Rd. near Butte	Republic Steel

Continued on next page

CULVERT NO.	GAGE	TYPE	SIZE, FEET	HIGHWAY NO., PROJECT NO. AND STATION	COUNTY	CREEK NAME	DESCRIPTION OF LOCATION	MANUFACTURER
8	10	SPPE	8.0	191, F 33(18), 1731 + 73	Phillips	Duval	4.7 mi. S. Last Chance Bar	ARMCO
9	10	SPPE	10.0	191, F 333(18), 1815 + 45	Phillips		3 mi. S. Last Chance Bar	ARMCO
10	10	SPPE	11.0	93, F 259(8), 611 + 00	Ravalli	Bass	4 mi. S. Florence	ARMCO
11	8	SPPA	12.33 x 7.75	93, F 259(8), 641 + 79	Ravalli	Larry	3.4 mi. S. Florence	ARMCO
12	8	SPPA	12.67 x 8.08	93, F 259(8), 743 + 06	Ravalli	Sweeney	1.5 mi. S. Florence	ARMCO
13	10	SPPA	9.33 x 6.25	S 10(3), 8 + 92	Missoula	Mill	In Frenchtown on Secondary Rd.	Bethlehem Steel Co.
14	10	SPPE	10.0	316, DF 258(11), 773 + 89	Carbon	Jack	11.8 mi. S. Bridger	ARMCO
15	8	SPPE	15.0	316, DF 258(11), 964 + 24	Carbon	Jack	7.8 mi. S. Bridger	ARMCO

Continued on next page

CULVERT NO.	GAGE	TYPE	SIZE, FEET	HIGHWAY NO., PROJECT NO. AND STATION	COUNTY	CREEK NAME	DESCRIPTION OF LOCATION	MANUFACTURER OF CULVERT PLATES
16	10	SPPC	7.0	87, F 212(11), 863 + 69	Big Horn	Sunday	1.5 mi. N. of Lodge Grass	Republic Steel Co.
17	10	SPPC	7.0	87, F 212(11), 433 + 08	Big Horn	Long Otter	9.8 mi. N. of Lodge Grass	Republic Steel Co.
18	10	SPPA	11.42 x 7.25	87, IN 90-9(5)489, 735 + 43	Big Horn		1 mi. N. of Crow Agency	ARMCO
19	10	SPPE	12.0	47, F 46(4), 928 + 50	Big Horn	Sorrel Horse	10.1 mi. S. Jct. U.S. 10 & Mont. 47	Republic Steel Co.
20	8	SPPE	12.0	47, F 46(4), 983 + 58	Big Horn	Mission	9 mi. S. of Jct. U.S. 10 & Mont. 47	Republic Steel Co.
21	10	SPPE	10.0	47, F 46(4), 1080 + 00	Yellow-stone		7.1 mi. S. Jct. U.S. 10 & Mont. 47	Republic Steel Co.
22	10	SPPE	10.0	47, F 46(4), 1145 + 80	Yellow-stone		5.7 mi. S. Jct. U.S. 10 & Mont. 47	Republic Steel Co.
23	8	SPPE	10.0	47, F 46(4), 1194 + 15	Yellow-stone		4.7 mi. S. Jct. U.S. 10 & Mont. 47	Republic Steel Co.

Continued on next page

CULVERT NO.	GAGE	TYPE	SIZE, FEET	HIGHWAY NO., PROJECT NO. AND STATION	COUNTY	CREEK NAME	DESCRIPTION OF LOCATION	MANUFACTURER OF CULVERT PLATES
24	8	SPPE	15.0	94, I 94-7(1)233, 444 + 50	Wibaux		1 mi. E. of Wibaux	Republic Steel Co.
25	8	SPPE	15.0	10, F 158(8), 768 + 00	Custer	Deep	N.E. Miles City	ARMCO
26	8	SPPE	15.0	10, F 158(8), 706 + 20	Custer	Dixon	N.E. Miles City	ARMCO
27	8	SPPE	12.0	10, F 158(8), 595 + 95	Custer	Spring	N.E. Miles City	ARMCO
28	8	SPPE	15.0	332, S 45(4), 1810 + 50	Custer	Lay	About 40 mi. S. Miles City	ARMCO
29	8	SPPA	11.83 x 7.58	294, S 14(8), 229 + 12	Meagher	S. Fork Smith R.	4 mi. E. of 89 towards Martinsdale	
30	10	SPPC	8.0	294, S 14(8), 645 + 49	Meagher	S. Fork Mus-selshell	10 mi. E. of 89 towards Martinsdale	
31	10	SPPC	10.0	294, S 14(8), 690 + 50	Meagher	Bozeman Fork of Mussel-shell	11.0 mi. E. of 89 towards Martinsdale	

Continued on next page

CULVERT NO.	GAGE	TYPE	SIZE, FEET	HIGHWAY NO., PROJECT NO. AND STATION	COUNTY	CREEK NAME	DESCRIPTION OF LOCATION	MANUFACTURER OF CULVERT PLATES
32	10	SPPE	7.0	S 174(2), 559 + 00	Wheat-land	Galloway	11.4 mi. E. of Judith Gap	Republic Steel Co.
33	10	SPPE	9.0	S 174(2), 491 + 50	Wheat-land	West Galloway	10 mi. E. of Judith Gap	Republic Steel Co.
34	10	SPPA	8.17 x 5.83	S 174(2), 424 + 30	Wheat-land	Blake	8.7 mi. E. of Judith Gap	Republic Steel Co.
35	8	SPPA	12.67 x 7.67	236, S 68(3), 862 + 14	Fergus	Dog	S. edge of Suffolk	Republic Steel Co.
36	8	SPPA	12.67 x 7.67	236, S 68(3), 942 + 43	Fergus	Dog	1 mi. N. of Suffolk	Republic Steel Co.
37	7	SPPA	14.33 x 7.33	236, S 68(3), 1212 + 33	Fergus	Dog	1 mi. S.E. of Winifred	Republic Steel Co.
38	10	SPPE	10.0	S 261(2), 98 + 82	Fergus	S. Fork Big Spring	4 mi. S.E. of Lewistown	ARMCO
39	10	SPPE	10.0	S 19(1), 179 + 10	Fergus		3 mi. S.E. of Lewistown	

Continued on next page

CULVERT NO.	GAGE	TYPE	SIZE, FEET	HIGHWAY NO., PROJECT NO. AND STATION	COUNTY	CREEK NAME	DESCRIPTION OF LOCATION	MANUFACTURER
40	8	SPPE	10.0	10, F 158(8), 817 + 25	Custer		1 mi. E. of Deep Cr., N. E. Miles City	ARMCO
41	7	SPPA	16.0 x 10.0	10, F 158(8), 884 + 24	Custer		2.2 mi. E. of Deep Cr., N. E. Miles City	ARMCO
42	8	SPPC	13.75	254, S 32(7), 304 + 23	Dawson		5.9 mi. N.W. Jct. 16 & 254	ARMCO
43	7	SPPE	13.0	254, S 32(7), 368 + 84	Dawson		7.4 mi. N.W. Jct. 16 & 254	ARMCO
44	8	SPPE	12.0	20, F 391(9), 1007 + 40	Dawson	Sullivan	8.5 mi. W. of Richey	ARMCO
45	10	SPPE	7.0	24, F 315(9), 346 + 35	McCone		.75 mi. S. Spillway of Ft. Peck Dam	Republic Steel Co.
46	10	SPPE	10.0	2, F 84(21), 1461 + 50	Roose-velt		7.1 mi. W. of Wolf Point	ARMCO
47	10	SPPE	10.0	2, F 84(21), 1536 + 08	Roose-velt		5.4 mi. W. of Wolf Point	ARMCO

Continued on next page

CULVERT NO.	GAGE	TYPE	SIZE, FEET	HIGHWAY NO., PROJECT NO. AND STATION	COUNTY	CREEK NAME	DESCRIPTION OF LOCATION	MANUFACTURER OF CULVERT PLATES
48	10	SPPE	7.0	201, S 361(8), 796 + 60	Richland		15.7 mi. E. Jct. 13 & 201	ARMCO
49	10	SPPE	10.0	201, S 361(6), 1812 + 00	Richland	West Charlie	24 mi. W. of Highway 16 on 201	ARMCO
50	5	SPPA	16.67 x 10.0	2, F 84(27), 1406 + 50	Roose-velt		8 mi. E. Cul-bertson on U. S. 2	Republic Steel Co.
51	10	SPPE	10.0	424, S 228(1), 756 + 33	Lewis & Clark	South Fork Dearborn	On Highway 424	Republic Steel Co.
52	10	SPPE	7.0	S 245(1), 767 + 92	Hill		2.5 mi. S. of Gildford	ARMCO
53	--	RCP	6.0	S 70(1), 258 + 96	Hill		6.5 mi. S. of Havre	
54	10	SPPE	9.0	376, S 187(1), 2363 + 95	Blaine	Whitebear Coulee	8.1 mi. S. of U.S. 2 on 376	ARMCO
55	10	SPPA	7.83 x 5.67	376, S 187(1), 2122 + 72	Blaine		13.1 mi. S. of U.S. 2 on 376	ARMCO

CAMBERS, SLOPES, OUTLET SCOUR HOLE SIZES AND SEDIMENT DEPTHS FOR CULVERTS OF THE LARGE CULVERT RESEARCH PROJECT

CULVERT NO.	CAMBER*, FEET		SLOPES				OUTLET SCOUR HOLE SIZE, FEET (LENGTH x WIDTH x DEPTH)	SEDIMENT DEPTH, FEET		
			CULVERT		STREAM BED					
	INITIAL**	PRESENT	INITIAL**	PRESENT	UPSTR.	DOWNSTR.		INLET	MIDDLE	OUTLET
1	0	0	.0114	.0225	.0337	.0468	50 x 25 x 4	1.0	0	0
2	0	-.20	.0032	.0016	.0087		40 x 30 x 4.5	0	0	0
3	-.10	-.87	.0133	.0167	.0108	.0035		0	0	0
4	-.10	-.90	.0085	.0086	.0207		28 x 60 x 4	0	.5	.7
5	0	---	.0247	.0262	.029	.0075		0	0	0
6	-.10	---	.0326	0326	.0239			0	0	0
7	0	---	.0042	.0027	.0036	.004	None	4.8	4.5	4.4
8	0	-.11	.0076	.0084	.0024	.0235	20 x 20 x 6	0	0	0
9	0	-.32	.0030	.004	.0094	.0026	20 x 20 x 1	0	.2	0
10	0	-.35	.0208	.0198	.0655	.0435	None	0	0	0
11	0	0	.0208	.0208	.0075	.0068	None	0	0	0

Continued on next page

* The camber is a measure at the middle of the culvert, of the vertical distance from a straight line between the inlet and outlet, minus indicating the measure is down from the straight line and positive indicating the measure is up from the straight line.

** Taken or calculated from plans or construction notes.

NOTE: This summary pertains to data collected during the summer of 1963. Also, the blanks indicate that not enough data was available to make an entry.

CULVERT NO.	CAMBER, FEET		SLOPES				OUTLET SCOUR HOLE SIZE, FEET (LENGTH x WIDTH x DEPTH)	SEDIMENT DEPTH, FEET		
			CULVERT		STREAM BED					
	INITIAL	PRESENT	INITIAL	PRESENT	UPSTR.	DOWNSTR.		INLET	MIDDLE	OUTLET
12 Left	0	-.53	.0125	.026	.0318	.009	None	0	.8	1.2
12 Right	0	0	.0125	.026	.0318	.009	None	2.0	2.0	2.0
13	0	+.10	.0175	.004	.0045	.0047	60 x 50 x 4	0	0	0
14 Left	0	---	.0078	.0082	.0035	.0075	None	1.8	1.9	2.0
14 Right	0	-.22	.0078	.0085	.0035	.0075	None	0	.5	.8
15 Left	0	+.07	.0063	.0053	.0018	.0047	None	0	0	.4
15 Right	0	0	.0063	.0044	.0018	.0047	None	0	.4	.4
16	0	-.15	.003	.0046	.085		20 x 20 x 5	1.0	1.0	0
17	0	-.23	.0128	.0112	.0117	.007	None	0	0	0
18	0	-.25	--	.0102	.07	.0067	None	0	.5	0
19 Left	0	0	0	.0023	.021	.0056	None	1.0	.7	.5
19 Right	0	0	0	.0023	.022	.0056	None	1.2	.7	.5
20 Left	0	0	.0014	.0011	.0067	.0231		0	0	0
20 Right	0	0	.0014	.0008	.0067	.0231		0	0	0
21	-.35	-.44	.0066	.0067	.0142	.0017		0	0	0

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CULVERT NO.	CAMBER, FEET		SLOPES				OUTLET SCOUR HOLE SIZE, FEET (LENGTH x WIDTH x DEPTH)	SEDIMENT DEPTH, FEET		
			CULVERT		STREAM BED					
	INITIAL	PRESENT	INITIAL	PRESENT	UPSTR.	DOWNSTR.		INLET	MIDDLE	OUTLET
22	-.1	-.08	.0013	.0047	.0095	.0074		.7	0	.3
23	-.1	---	.021	.0019	.020	.0211		.8	1.2	.5
24 Left	0	---	.0088	.0078	.0015	.002	None	.5	.7	1.5
24 Right	0	---	.0088	.0078	.0015	.002	None	.7	.7	1.5
25	-.8	+.19	.0092	.0095	.0128			.2	0	0
26 Left	-.5	---	.0069	.006	.0034	.005	None	2.3	2.3	2.0
26 Right	-.5	---	.0069	.009	.0034	.005	None	1.5	1.7	1.4
27	-.9	---	.0087	.008	.018	.01	None	1.0	1.0	0
28 Left	-.15	---		.0082	.0069	.0061	100 x 100	4.6	4.7	4.7
28 Right	-.15	---		.0004	.0069	.0061	100 x 100	5.4	5.1	5.1
29	0	-.15	.0025	.001	.015	.007	15 x 20 x .5	1.5	1.3	1.1
30	0	-.23		.013	.005	.004	6 x 10 x 1.5	0	0	0
31	+.2	-.46	.0073	.0051	.019	.01	25 x 20 x 3	1.2	.5	0
32	0	-.24	.024	.024	.0128		50 x 8 x 1	0	0	0
33	0	-.37	.0182	.0076	.016	.0116	2 x 8 x 2	0	.5	0

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CULVERT NO.	CAMBER, FEET		SLOPES				OUTLET SCOUR HOLE SIZE, FEET (LENGTH x WIDTH x DEPTH)	SEDIMENT DEPTH, FEET		
			CULVERT		STREAM BED					
	INITIAL	PRESENT	INITIAL	PRESENT	UPSTR.	DOWNSTR.		INLET	MIDDLE	OUTLET
34	0	-.08	.0072	.0055	.025	.0165	10 x 6 x 1	.0	.3	0
35 Left	-.1	-.07		.0013	.016	.0025	3 x 2 x .5	0	.2	.1
35 Right	-.1	-.10		.00	.016	.0025	3 x 2 x .5	0	.1	.2
36 Left	0	---	.0055				None	.5	.7	1.0
36 Right	0	---	.0055				None	2.0	1.0	.5
37 Left	+.05	0		.0053	.014	.01		0	0	0
37 Right	+.05	0		.0061	.014	.01		0	0	0
38 Left	0	-.11	.020	.011	.006	.0018	40 x 45 x 4	0	0	0
38 Right	0	---	.020	.011	.006	.0018	40 x 45 x 4	0	0	0
39	+.6	-.38	.0167	.013	.003	.0615	8 x 6 x 3	0	.5	0
40	-.9	0	.0427	.04	.0123	.0053	30 x 20 x 4	0	0	0
41 Left	-.4	---	.0133	.0078	.013	.0045	Huge, 2 deep	0	0	0
41 Right	---	+.46	.0133	.014	.013	.0045	Huge, 2 deep	0	0	0
42	---	---		.0152	.0023	.0092	None	0	1.2	1.0
43	-.4	---	0	.0015	.0036	.012		3.0	4.0	3.0

Continued on next page

CULVERT NO.	CAMBER, FEET		SLOPES				OUTLET SCOUR HOLE SIZE, FEET (LENGTH x WIDTH x DEPTH)	SEDIMENT DEPTH, FEET		
			CULVERT		STREAM BED					
	INITIAL	PRESENT	INITIAL	PRESENT	UPSTR.	DOWNSTR.		INLET	MIDDLE	OUTLET
44 Left	---	---	0	0	.004	.0043	None	.2	.2	.2
44 Right	---	---	0	.003	.004	.0043	None	.5	.5	.5
45	0	-.48	.0187	.018	.009	.025	30 x 20 x 5	0	0	0
46	-.25	-.12	.020	.0115	.006	.0006	40 x 20 x 4	0	0	0
47	0	-.10	.0154	.0054	.0024	.0013	30 x 20 x 5	0	0	0
48	0	0	.0064	.0074	028		40 x 20 x 4	.5	.3	0
49	-.25	-.12	.005	.007	.0022	.0156	30 x 30 x 3	0	.3	.1
50	0	---	.004	.0012	.003	.0017	None	1.0	.7	.3
51 Left	0	+.19	.0038	.011	.014	.0067		0	0	0
51 Right	0	-.21	.0038	.009	.014	.0067		0	.3	0
52	---	-.27	.0046	.009	.042	.03	40 x 30 x 8	0	.3	0
53	0	---	.0253	.02	.008	.0125	None	0	0	0
54 Left	0	-.21	0	.002	.002	.0034	5 x 10 x .5	0	0	0
54 Right	0	-.28	0	.002	.002	.0034	5 x 10 x .5	0	0	0
55	0	+.17	.0028	.0005	.033	.0016	None	0	0	0

DEFLECTIONS, FILL HEIGHTS, SOIL TYPES AND LENGTHS
FOR CULVERTS OF THE LARGE CULVERT RESEARCH PROJECT

CULVERT NO.	TYPE	DIMENSIONS, FEET				% CHANGE, NEAREST 1%		FILL** HEIGHT, FEET	FILL SOIL TYPE, FIELD CLASSIFICATION	LENGTH, FEET
		ORIGINAL		PRESENT						
		HEIGHT*	WIDTH*	HEIGHT*	WIDTH*	HEIGHT*	WIDTH*			
1	SPPA	10.08	16.58	9.60 9.18 9.60	16.66 17.0 16.33	5 9 5	--- 3 2	6.5	Gravelly, sandy, silt	88
2	SPPE	7.88	7.12	7.75 7.71 7.84		2 2 1		10.0	Sandy silt	104
3	RCP	9.00	9.00	9.00 9.00 9.00		0 0 0		24.0	Sandy, gravelly silt	150
4	RCP	9.00	9.00	9.00 9.00 9.00		0 0 0		17.0	Silty sand	118
5	SPPE	7.61	6.89	7.37 7.05 7.25		3 7 5		19.0	Sand, silty clay	170

* The top number refers to the inlet, the middle number to the middle and the bottom number to the outlet of the culvert.

** Above top of culvert.

Continued on next page

CULVERT NO.	TYPE	DIMENSIONS, FEET				% CHANGE, NEAREST 1%		FILL HEIGHT, FEET	FILL SOIL TYPE, FIELD CLASSIFICATION	LENGTH, FEET
		ORIGINAL		PRESENT						
		HEIGHT	WIDTH	HEIGHT	WIDTH	HEIGHT	WIDTH			
6	SPPE	9.45	8.55					9.5	Silt, rock flour	170
7	SPPC	11.00	11.00					22.0	Silty sand	144
8	SPPE	8.40	7.60	8.25 8.21 8.25		2 2 2		13.8	Clay and rotten shale	132
9	SPPE	10.50	9.50	10.53 10.29 10.46		0 2 0		21.8	Clay and rotten shale	166
10	SPPE	11.55	10.45	12.00 11.50 11.66		4 0 1		2.0	Boulder and gravelly sand	96
11	SPPA	7.75	12.33	7.66 7.66 7.75		1 1 0		7.1	Natural boulder and sandy gravel	96
12 Left	SPPA	8.08	12.67	8.33 8.33 8.33		3 3 3		2.0	Natural boulder and sandy gravel	80

Continued on next page

CULVERT NO.	TYPE	DIMENSIONS, FEET				% CHANGE, NEAREST 1%		FILL HEIGHT, FEET	FILL SOIL TYPE, FIELD CLASSIFICATION	LENGTH, FEET
		ORIGINAL		PRESENT						
		HEIGHT	WIDTH	HEIGHT	WIDTH	HEIGHT	WIDTH			
12 Right	SPPA	8.08	12.67		12.66		0	2.0	Natural boulder and sandy gravel	80
13	SPPA	6.25	9.33	6.25 6.17 6.50		0 1 4		6.0	Dirty, sandy gravel	80
14 Left	SPPE	10.50	9.50					13.2	Sandy silt; some gravel	128
14 Right	SPPE	10.50	9.50	10.60 10.50 10.50		1 0 0		13.2	Sandy silt; some gravel	128
15 Left	SPPE	15.75	14.25	15.75 15.45 15.60		0 2 1		7.0	Clay, est. PI = 14	160
15 Right	SPPE	15.75	14.25	15.80 15.70 15.80		0 0 0		7.0	Clay, est. PI = 14	160
16	SPPC	7.00	7.00	6.83 6.83 6.92		2 2 1		9.7	Silty sand and gravel	100

Continued on next page

CULVERT NO.	TYPE	DIMENSIONS, FEET				% CHANGE, NEAREST 1%		FILL HEIGHT, FEET	FILL SOIL TYPE, FIELD CLASSIFICATION	LENGTH, FEET
		ORIGINAL		PRESENT						
		HEIGHT	WIDTH	HEIGHT	WIDTH	HEIGHT	WIDTH			
17	SPPC	7.00	7.00	6.96 6.83 6.92		1 2 1		10.7	Sandy silt	94
18	SPPA	7.25	11.42	7.00 6.86 7.08		3 5 2		5.2	Dirty gravel	100
19 Left	SPPE	12.60	11.40		11.50 11.66 11.58		1 2 2	10.7	Gravelly, sandy silt	112
19 Right	SPPE	12.60	11.40		11.58 11.83 11.66		2 4 2	10.7	Gravelly, sandy silt	112
20 Left	SPPE	12.60	11.40	12.54 12.33 12.58		0 2 0		11.5	Medium plastic silt	140
20 Right	SPPE	12.60	11.40	12.46 12.50 12.54		1 1 0		11.5	Medium plastic silt	140
21	SPPE	10.50	9.50	10.25 10.18 10.50		2 3 0		13.6	Gravelly, sandy silt	136

Continued on next page

CULVERT NO.	TYPE	DIMENSIONS, FEET				% CHANGE, NEAREST 1%		FILL HEIGHT, FEET	FILL SOIL TYPE, FIELD CLASSIFICATION	LENGTH, FEET
		ORIGINAL		PRESENT						
		HEIGHT	WIDTH	HEIGHT	WIDTH	HEIGHT	WIDTH			
22	SPPE	10.50	9.50	10.08	10.08 9.92	4	6 5	19.2	Gravelly, sandy silt	160
23	SPPE	10.50	9.50		9.83 10.33 9.66		4 8 2	30.4	Gravelly silt (Med. plastic)	200
24 Left	SPPE	15.75	14.25					10.9	Rotten shale; sandy	160
24 Right	SPPE	15.75	14.25					10.9	Rotten shale; sandy	160
25	SPPE	15.75	14.25	15.54 15.47 15.85		1 2 1		33.0	Stony, sandy silt	168
26 Left	SPPE	15.75	14.25		14.83 14.92 14.58		4 5 2	10.4	Sandy gravel	144
26 Right	SPPE	15.75	14.25		14.50 15.08 15.08		2 6 6	10.4	Sandy gravel	144

Continued on next page

CULVERT NO.	TYPE	DIMENSIONS, FEET				% CHANGE, NEAREST 1 %		FILL HEIGHT, FEET	FILL SOIL TYPE, FIELD CLASSIFICATION	LENGTH, FEET
		ORIGINAL		PRESENT						
		HEIGHT	WIDTH	HEIGHT	WIDTH	HEIGHT	WIDTH			
27	SPPE	12.60	11.40		11.83 12.42 12.00		4 9 5	56.0	Gravelly clay	256
28 Left	SPPE	15.75	14.25		14.42 14.92 14.66		1 5 3	2.6	Sandy clay	90
28 Right	SPPE	15.75	14.25		14.66 14.83 14.54		3 4 2	2.6	Sandy clay	90
29	SPPA	7.58	11.83		11.83 12.0 12.0		0 1 1	2.0	Gravelly silt to clay	80
30	SPPC	8.00	8.00	7.94 7.28 7.87		1 9 2		28.5	Sandy, rocky silt	150
31	SPPC	10.00	10.00	9.90 9.87 9.87		1 1 1		11.0	Silty rock	96
32	SPPE	7.35	6.65	7.37 7.25 7.44		0 1 1		9.7	Silty gravel	108

Continued on next page

CULVERT NO.	TYPE	DIMENSIONS, FEET				% CHANGE, NEAREST 1%		FILL HEIGHT, FEET	FILL SOIL TYPE, FIELD CLASSIFICATION	LENGTH, FEET
		ORIGINAL		PRESENT						
		HEIGHT	WIDTH	HEIGHT	WIDTH	HEIGHT	WIDTH			
33	SPPE	9.45	8.55	9.50 9.42 9.50		1 0 1		6.0	Gravelly silt	88
34	SPPA	5.83	8.17	5.83 5.75 5.83		0 1 0		1.33	Gravelly silt	56
35 Left	SPPA	7.67	12.67	7.63 7.42 7.58		1 3 1		3.8	Silt; some gravel	68
35 Right	SPPA	7.67	12.67	7.50 7.42 7.63		2 3 1		3.8	Silt; some gravel	68
36 Left	SPPA	7.67	12.67		12.75 13.00 12.75		1 3 1	5.5	Silt	72
36 Right	SPPA	7.67	12.67		12.75 13.00 12.75		1 3 1	5.5	Silt	72
37 Left	SPPA	8.33	14.33	8.33 7.87 8.29		0 6 0		7.0	Silt	88

Continued on next page

CULVERT NO.	TYPE	DIMENSIONS, FEET				% CHANGE, NEAREST 1%		FILL HEIGHT,	FILL SOIL TYPE, FIELD CLASSIFICATION	LENGTH, FEET
		ORIGINAL		PRESENT						
		HEIGHT	WIDTH	HEIGHT	WIDTH	HEIGHT	WIDTH			
37 Right	SPPA	8.33	14.33	8.33 7.87 8.28		0 6 1		7.0	Silt	88
38 Left	SPPE	10.50	9.50	10.42 10 21 10.33		1 3 2		7.9	High plastic silt	100
38 Right	SPPE	10.50	9.50		9.58 9.66 9.50		1 2 0	7.9	High plastic silt	100
39	SPPE	10.50	9.50	10.33 10.25 10.33		2 2 2		6.0	Rotten shale or sand-stone	90
40	SPPE	10.50	9.50	10.42 9.88 10.50		1 6 0		30.5	Sandy silt	190
41 Left	SPPA	10.00	16.00		15.77 16.04 15.71		1 0 2	6.5	Gravelly silt	92
41 Right	SPPA	10.00	16.00	10.08 9.42 10.00		1 6 0		6.5	Gravelly silt	92

Continued on next page

CULVERT NO.	TYPE	DIMENSEIONS, FEET				% CHANGE, NEAREST 1%		FILL HEIGHT, FEET	FILL SOIL TYPE, FIELD CLASSIFICATION	LENGTH, FEET
		ORIGINAL		PRESENT						
		HEIGHT	WIDTH	HEIGHT	WIDTH	HEIGHT	WIDTH			
42	SPPC	13.75	13.75		14.18 14.92 14.18		3 9 3	16.5	Low plas. silt to h. p. clay	142
43	SPPE	13.65	12.35		13.17 13.33 13.17		7 8 7	7.7	High plas. silt; sandy silt	93
44 Left	SPPE	12.60	11.40	12.33 11.58	 11.58	2 8	 2	22.0	Low plastic clay	156
44 Right	SPPE	12.60	11.40	12.24 11.58	 11.50	3 8	 1	22.0	Low plastic clay	156
45	SPPE	7.35	6.65	7.04 6.71 7.00		4 9 5		14.0	Clay and shale	112
46	SPPE	10.50	9.50	10.46 10.42 10.58		0 1 1		3.0	Low plastic clay	100
47	SPPE	10.50	9.50	10.54 10.42 10.47		0 1 0		15.2	Clay-med. plastic	130

Continued on next page

CULVERT NO.	TYPE	DIMENSIONS, FEET				% CHANGE, NEAREST 1%		FILL HEIGHT, FEET	FILL SOIL TYPE, FIELD CLASSIFICATION	LENGTH, FEET
		ORIGINAL		PRESENT						
		HEIGHT	WIDTH	HEIGHT	WIDTH	HEIGHT	WIDTH			
48	SPPE	7.35	6.65	7.32		0 5 0		29.0	Sandy silt	156
49	SPPE	10.50	9.50	10.25 10.04 10.17		2 4 3		8.0	Silt-low plastic	100
50	SPPA	10.00	16.66		16.66 16.83 16.75		0 1 1	4.7	Med. plastic clay	100
51 Left	SPPE	10.50	9.50	10.50 10.00 10.25		0 5 2		27.8	Gravelly, sandy silt	160
51 Right	SPPE	10.50	9.50	10.42 10.88 10.25		1 4 2		27.8	Gravelly, sandy silt	160
52	SPPE	7.35	6.65	7.25 7.04 7.58		1 4 3		21.0	Sandy-low plas. clay	130
53	RCP	6.00	6.00	6.00 5.50 6.00		0 8 0		32.0	High plastic clay	150

Continued on next page

CULVERT NO.	TYPE	DIMENSIONS, FEET				% CHANGE, NEAREST 1%		FILL HEIGHT, FEET	FILL SOIL TYPE, FIELD CLASSIFICATION	LENGTH, FEET
		ORIGINAL		PRESENT						
		HEIGHT	WIDTH	HEIGHT	WIDTH	HEIGHT	WIDTH			
54 Left	SPPE	9.45	8.55	9.42 9.08 9.33		0 4 1		13.5	Silt	124
54 Right	SPPE	9.45	8.55	9.33 9.08 9.33		1 4 1		13.5	Silt	124
55	SPPA	5.67	7.83	5.63 5.63 5.66		1 1 0		3.0	Silt to clay	72

CULVERT PROBLEMS

With few exceptions, each of the 55 Large Culvert Research Project culverts had a problem of some type, and in some cases, more than one. These problems included:

Piping
Scour holes
Fill erosion
Cracked plates
Sediment deposits
Corrosion

Table D I is a summary of how many culverts had the various problems.

Table DI. NUMBER OF CULVERTS WITH VARIOUS PROBLEMS.

PROBLEM	NO. OF CULVERTS WITH PROBLEM
Piping	6
Scour holes	29
Fill erosion	27
Cracked plates	6
Sediment deposits	19
Corrosion	6

Following is an explanation of the problems that have not already been discussed in the main body of the thesis, supported with pictures of the described problem.

Scour Holes

As water leaves a culvert outlet, the velocity may be high enough to scour or erode the soil in the stream bed. Eddy currents may develop, causing an undermining of the stream banks and culvert. Continued scour

and undermining will enlarge the stream channel, the enlargement being called a scour hole (See Figures D1, D2, D3, D4 and D5).

Scour holes may also develop at culvert inlets due to hydraulic conditions which cause eddy currents at the sides of the entrance.

Figure D1. OUTLET SCOUR HOLE AT THE MUSKRAT CREEK CULVERT.

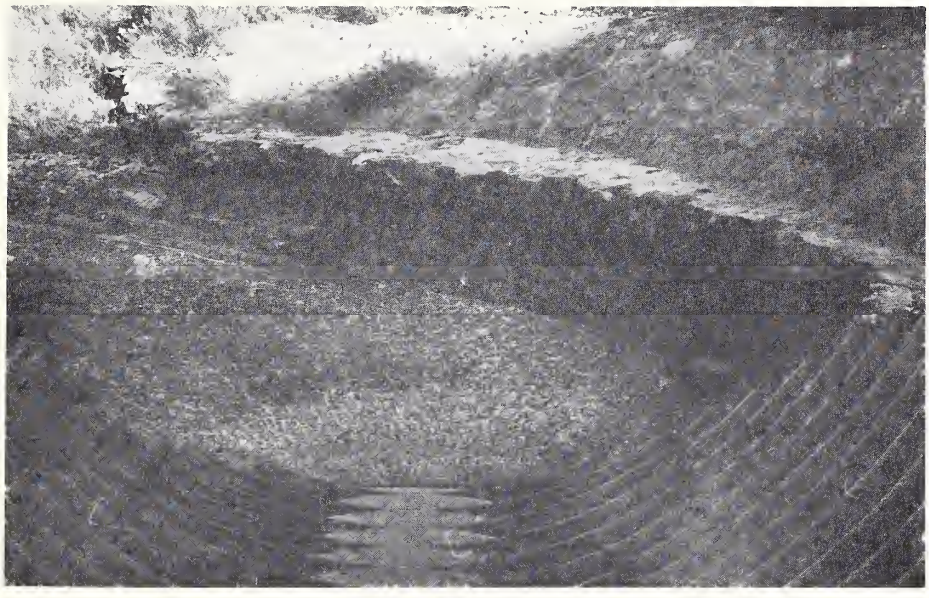

Figure D2. OUTLET SCOUR HOLE AT CULVERT NO. 40.

Notice how the grouted riprap has been washed away.

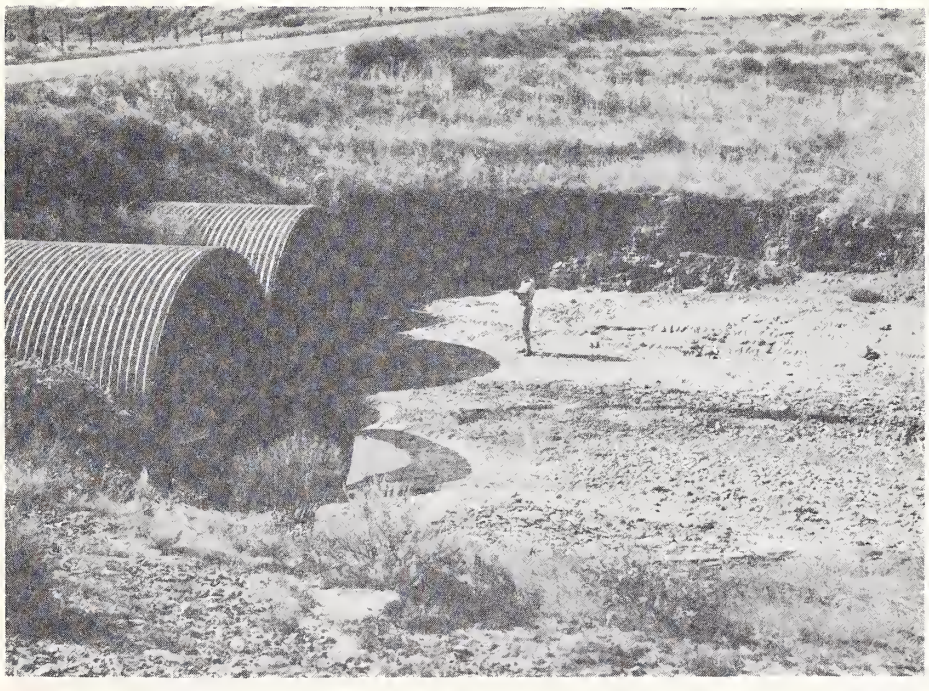

Figure D3. OUTLET SCOUR HOLE AT CULVERT SITE NO. 41.

A grouted riprap apron has been carried completely away and the culverts are undermined.

Figure D4. OUTLET OF CULVERT NO. 52.

The soil has been eroded away from the sides of the culvert, leaving a prism of soil supported on top of the culvert at the outlet.

Figure D5. OUTLET SCOUR HOLE AT A CULVERT IN CENTRAL MONTANA.

Fill Erosion

Water draining from a roadway down a fill slope will erode the fill material; the amount of erosion depending on the concentration of draining water and the erodibility of the soil. The pictures in Figures D6 and D7 show fill erosion.

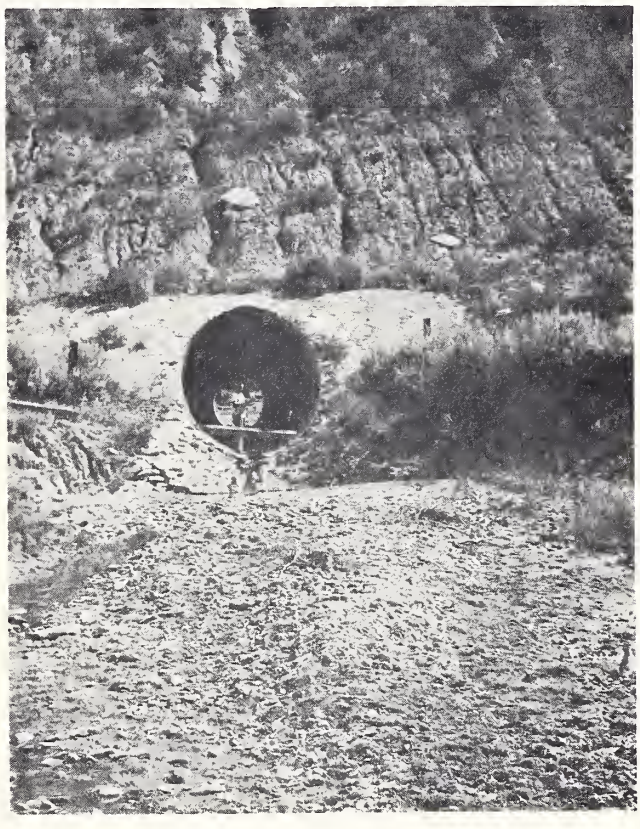

Figure D6. FILL EROSION AT CULVERT NO. 27.

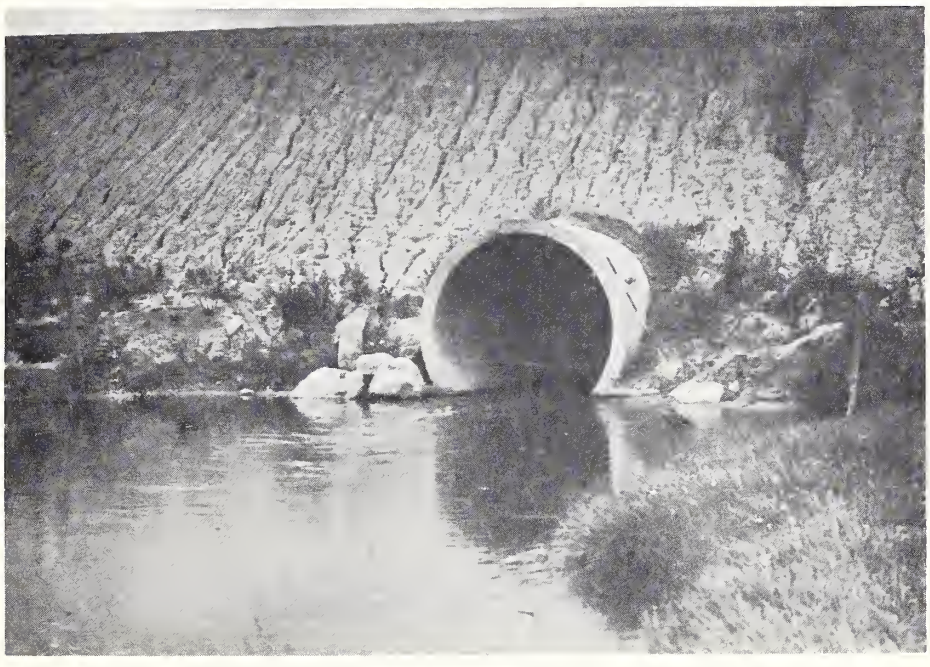

Figure D7. FILL EROSION AT CULVERT NO. 4.

Corrosion

The loss of metal by chemical action is called corrosion, and will shorten a culvert's life. Corrosion can take place where corrosive soil is placed next to a culvert or where corrosive water comes in contact with a culvert.

Figure D8 shows localized corrosion that has caused holes to develop in the walls of a culvert. Figure D9 shows another type of corrosion which has reduced the thickness of the metal as much as 50 percent in some cases.

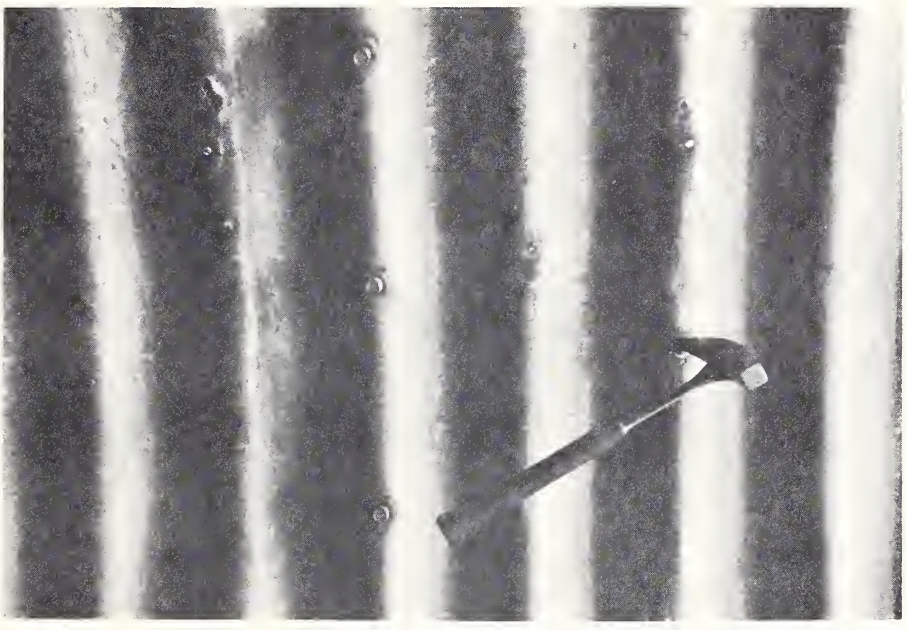

Figure D8. LOCALIZED CORROSION SPOTS IN CULVERT NO. 45.

The geologist's pick could easily penetrate the walls of the culvert at these localized corrosion spots.

Figure D9. CORROSION NODULES IN CULVERT NO. 10.

Under these nodules the metal was eaten away and in some cases reduced the thickness of the culvert by as much as 50 percent.

Sediment Deposits

Water will carry suspended particles of small sizes and roll particles of larger sizes along the bottom of a stream bed. The amount of particle movement will depend on the amount and velocity of the water. When the velocity is reduced, the particles will settle out or stop rolling, causing a buildup called a sediment deposit (See Figures D10 and D11).

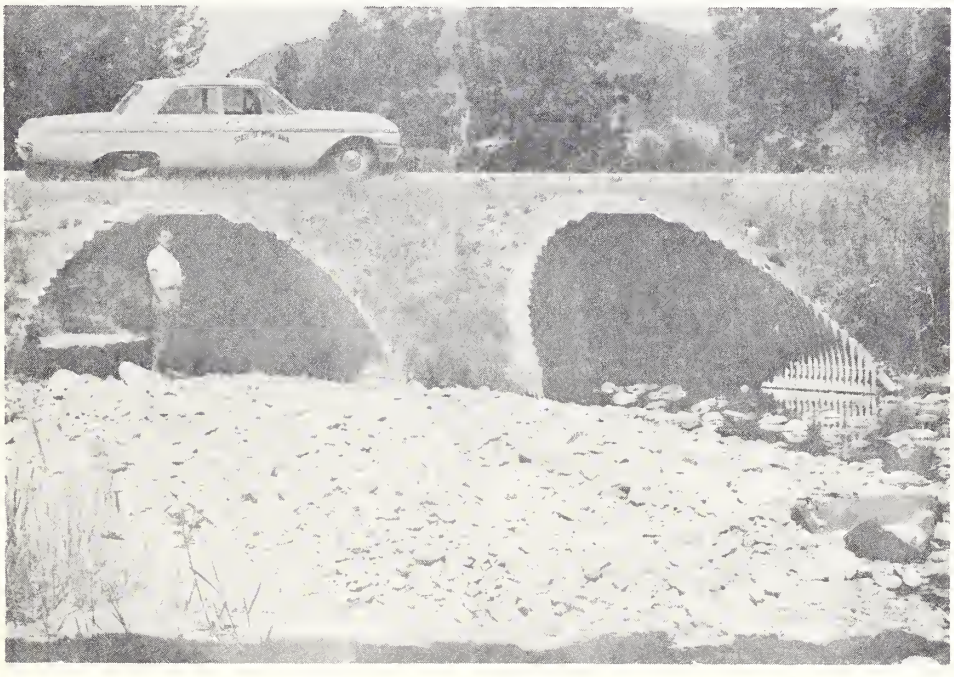

Figure D10. SEDIMENT DEPOSIT AT CULVERT NO. 12.

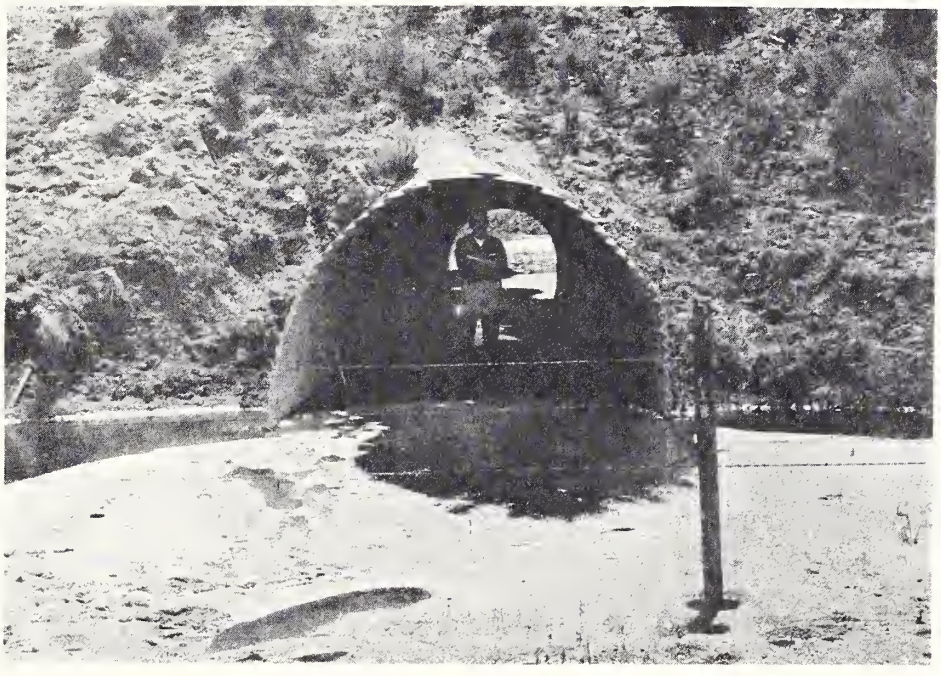

Figure D11. SEDIMENT DEPOSIT AT CULVERT NO. 7.

This 11-foot circular culvert had as much as four and one-half feet of sediment at places.

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